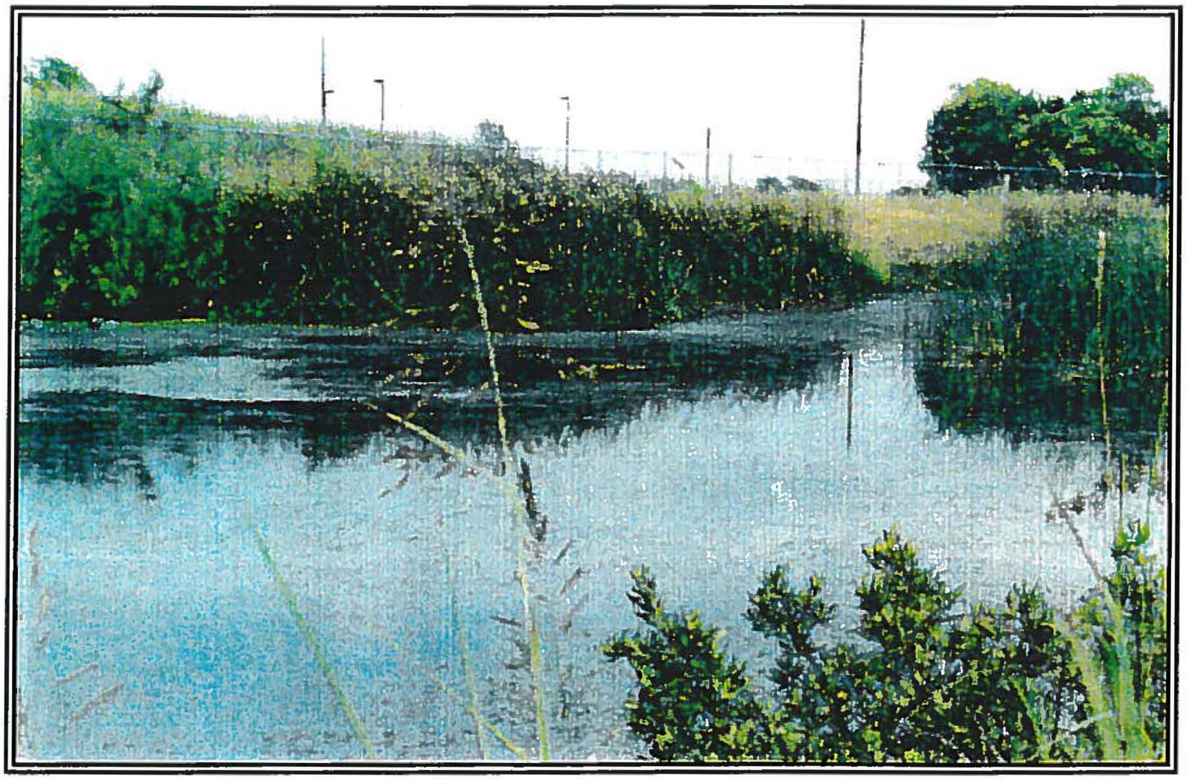
EVALUATION OF NONPOINT SOURCE CONTROLS, AN EPA/TNRCC SECTION 319 GRANT REPORT

Volume 1. Final Report



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Drainage Utility Department
Environmental Resources Management Division

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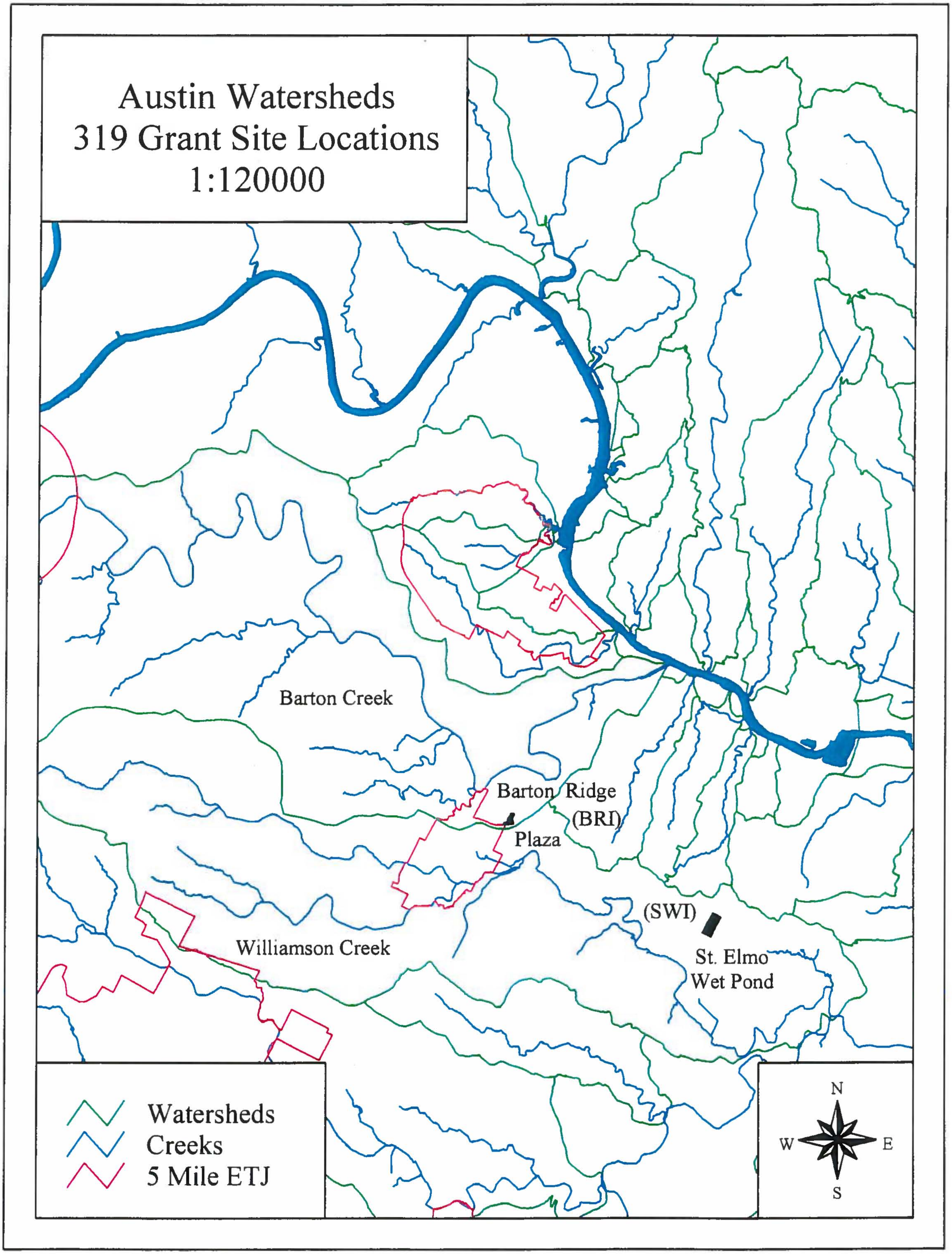
EVALUATION OF NON-POINT SOURCE CONTROLS AN EPA/TNRCC SECTION 319 GRANT PROJECT

EXECUTIVE SUMMARY

The City of Austin (COA) is committed to a multi-faceted approach to nonpoint source (NPS) pollution prevention and control, and has continuously made efforts to identify those controls that are effective in retaining pollutants carried by rainfall runoff from the urban area. In 1990, the City of Austin Environmental and Conservation Services Department applied for and obtained a $150,000 EPA Section 319 Nonpoint Source Management Program matching grant. The project scope included implementation, monitoring, and effectiveness evaluation of both structural and nonstructural Best Management Practices (BMPs). As part of the grant, the City of Austin provided for the transfer of knowledge gained from the project by means of educational outreach efforts, presentations, and publications.

Two structural BMPs for retrofitting urban areas were selected for study as part of this grant, a retrofitted wet detention pond at the City's St. Elmo service center in the Williamson Creek watershed and a sedimentation/filtration pond at Barton Ridge Plaza in the Barton Creek watershed. Although these watersheds are not considered urban (see figure), the drainage areas of the ponds themselves represent accurately a typical urban retrofit situation. These two facilities both demonstrated state-of-the-art design of two basically different pollutant removal mechanisms.

Barton Ridge Plaza ponds (BRP) consist of a sedimentation pond, a sand filtration basin, and a channel or splitter box which diverts the first 2/3-inch (approximately) runoff into sedimentation and allows the remaining portion of runoff to overflow through a side weir. St. Elmo was a flood control facility retrofitted as a wet pond by deepening and providing a permanent pool for water quality treatment. In addition, a littoral shelf was graded into the pond to provide a shallow area for introduction of aquatic vegetation. Vegetation was established according to a plan developed by City staff for appropriate wet pond landscape design.


Austin Watersheds
319 Grant Site Locations
1:120000
Barton Creek
Barton Ridge
(BRI)
Plaza
(SWI)
St. Elmo
Wet Pond
Williamson Creek
Watersheds
Creeks
5 Mile ETJ
N
W
E
S

The COA built four monitoring stations at Barton Ridge Plaza and three at St. Elmo. Remote controlled automatic monitoring stations were installed at the ponds to facilitate discrete sampling over the duration of representative storms. Flow was measured and samples were collected and analyzed according to the Quality Assurance Plan for this project. Methods were assessed for evaluation of treatment efficiencies of the water quality control basins. The following conclusions were drawn from the results of this analysis in conjunction with previous COA BMP studies

For a single runoff event, the outflow from a wet pond is the water stored from previous rainfall events and treated in the pond. Therefore, the grant project team computed treatment and/or annual removal efficiencies for St. Elmo Pond using the means of event mean concentrations (EMCs). The overall annual removal efficiencies for a wet pond are generally equivalent to the pond treatment efficiencies since no inflow by-passes or overflows from the pond. A summary table provides pond treatment efficiency values for the various pollutant parameters.

The removal efficiency of the pond for suspended solids is high, measured at 93 percent. For nutrients, values vary depending on the form of the constituent. For example, 87 percent of total phosphorus, 40 percent of nitrate-nitrite and 50 percent of total nitrogen were removed. St. Elmo pond has a permanent pool of 4.1 acre-feet which is equivalent to about 1.80-inch of runoff from the drainage area. The drainage area of the pond and its imperviousness are 27.11 acres and 66 percent, respectively. The hydraulic residence time of water in the permanent pool is substantially long at about 30 days, The draw-down time of water in the pond during a runoff event ranges from 20 to 70 hours, depending on the size of the runoff event.

Treatment efficiencies (see summary table) at the Barton Ridge Plaza ponds were best evaluated using a paired comparison of inflow and outflow event mean concentrations. The overall annual removal efficiencies for this pond system should be less than the measured treatment efficiencies since part of the runoff by-passes or overflows from the system. The treatment efficiency of total suspended solids (TSS) for this system

Summary Table

Computed Treatment Efficiencies for Barton Ridge Plaza Sand Filtration and St. Elmo Wet Ponds Using Measured Flow and Concentration Data (Efficiency in Percent)

Parameter	Barton Ridge Plaza * Sedimentation/Filtration System	St. Elmo Wet Pond
TSS	89	93
BOD	51	61
COD	55	50
NO_2+NO_3	-76	40
TKN	50	57
NH_3	53	91
TN	17	50
TP	59	87
DP	3	66
Cu	72	58
Pb	86	39
Zn	76	60

* The overall annual removal efficiency for the Barton Ridge Plaza pond system will be lower since a portion of the inflow by-passes or overflows the system without treatment. It is estimated that the annual removal efficiencies for the system will be about 20 percent lower than those listed in this table.

was measured at 89 percent. The overall annual removal efficiency of TSS was estimated to be 71 percent since 30% of the annual runoff by-passed the pond and this by-pass left 20% of the total load untreated. As expected, some dissolved forms of nutrients were not adequately removed by the filtration process. The overall annual removal efficiencies for total nitrogen and total phosphorus were about 14 percent and 47 percent, respectively. The splitter box and sedimentation basin for the pond system can ease the operation and maintenance of the sand filter. The sand filter itself is a filtration bed of adequate size, consisting of fine sand with underdrain pipes. The drainage area for this system is 2.95 acres with approximately 81% impervious cover.

One product of monitoring a control structure is identification of pollutant levels in the runoff draining to the pond. The presence or absence of certain pollutants can often help identify the sources. Some of the toxic constituents may be at levels which are below detection limits in the influent or the water column. However, due to the concentration of these pollutants through adsorption processes with inorganic and organic sediment particles, they may be easily identified in the settled sediments. Sediment in the St. Elmo wet pond was evaluated by constructing a set of sediment monitoring traps to collect the settled materials in the pond. Sediments were analyzed for toxics including lead, copper, zinc, iron and polynuclear aromatic hydrocarbons (PAHs).

Many types of metals were detected in sediment samples. Concentrations of these metals were generally higher than those in sediments sampled in other City wet ponds, but are comparable to levels found in oil/grit separators that capture runoff from similar land use areas. One important factor to note is that despite some elevated levels of toxics in the sediments, testing of sediments from other water quality controls in the City indicate that the toxics are strongly sorbed and all have passed TCLP tests (for landfill disposal criteria).

Other factors in addition to the removal efficiency need to be considered when evaluating the appropriateness of implementing BMPs. Factors to consider are the construction and maintenance costs, and the cost-effectiveness of the controls. Another important factor is the degree to which a facility treats different constituents. An overall assessment in the study indicates that large regional wet facilities are most cost-effective and treat a wide range of constituents. For smaller sites, a sedimentation/filtration system may be most appropriate with regular maintenance required. Other types of facilities may be applicable for pre-treatment or for particular instances where low capital cost is essential or where lack of space requires an underground system such as an oil/grit separator. A final consideration, which the City is beginning to examine, is the benefit in terms of downstream erosion control which will be gained from the different devices. Often, increased channel flows and sediment produced by subsequent channel erosion are the dominant source of loads in developed areas.

In addition to the implementation and evaluation of structural control devices, the grant project initiated nonstructural, pollution prevention programs. Programs initiated through this grant included educational materials, outreach efforts and citizen monitoring programs. Specific components of the programs included posters targeting both residential and commercial practices, television public service announcements highlighting environmentally friendly tips for landscaping and auto care, seminars for targeted business audiences, and education through the citizen monitoring program and Austin Youth River Watch. In addition, a phone survey was conducted to assist in focusing public outreach efforts for most effective behavior modification. A high percentage of respondents demonstrated a lack of knowledge about the fundamental principles of NPS pollution, water quality problems associated with disposal of organic debris in waterways, and method for proper disposal of petroleum products. In addition, a high percentage of respondents use pesticides and fertilizers, with approximately 50% applying them inappropriately before heavy rains.

Public education campaigns in years following this survey have targeted specific areas of concern revealed by the results.

ACKNOWLEDGMENTS

This report is part of the Section 319 grant project approved by the United States Environmental Protection Agency (EPA) under its Nonpoint Source Management Program. The Texas Natural Resource Conservation Commission (TNRCC) is the grantor and management Agency for this grant project. The TNRCC project management team consists of Arthur Talley, P.E., Leader of Nonpoint Source Pollution Management Program, and Valerie Robinson, Grant Project Officer. The total project cost is $250,000 including a matching fund of $100,000 from the City of Austin (COA). In addition, the COA has contributed a significant amount of additional funding and resources for completing this project.

The grant project team for the structural BMP study consists of the staff members of the City of Austin's Drainage Utility Department. Channy Soeur, P.E., a former staff member of the Drainage Utility, was Project Manager for the study during 1994-96 and has contributed significant work to the project. George C. Chang, P.E., is Project Manager for the storm water monitoring and data analysis projects. The grant team completed this report under the general supervision of Nancy McClintock, Manager of Environmental Resource Management (ERM) Division, Drainage Utility Department.

Richard Robinson, Baolin Bai, Kathy Luo, Truman Zhu, James Hubka, Javier Dalgado, Nevzat Turan, Sam Mahmoud, and Steve Manning of the grant team processed data collected from all storm water monitoring stations. Richard Robinson coordinated this difficult task. James Hubka, Truman Zhu, Richard Robinson, Kathy Luo, Nevzat Turan, Scott Mittman, Roger Glick, George Chang, and Leila Gosselink of the grant team analyzed data and prepared this report for the grant study. Leslie Tull, P.E., coordinated the designs of Barton Ridge Sedimentation and Filtration Pond and the associated flow monitoring structures. John Gleason designed the landscape work for St. Elmo Pond. Patrick Hartigan and Edward Peacock, P.E. of the Drainage Utility reviewed and provided valuable comments to the study.

Aboli Moezzi, Steve Manning, Sam Mahmoud, and Javier Delgado of the grant team conducted storm water monitoring operation for the study. Former Monitoring Section members (of the ERM Division) who participated in the planning, construction, and operation of the monitoring projects include Abdirahman Jama, James Lewis, William Burd, Vera Bryan, Bryan Davis, Rene Avila, and John Watkins. Many former staff members of the Environmental Resource Management Division led and contributed to the efforts for the nonstructural programs. Edward Peacock, Mike Lyday and Scott Hiers of the ERM Division compiled these efforts for the final report.

Finally, the grant team expresses deep appreciation to the U.S. Environmental Protection Agency, Project Officers Leonard Pardee and Brad Lamb, and the Texas Natural Resource Conservation Commission, Project Officers Arthur Talley and Valerie Robinson, for their involvement, technical guidance, and administrative support in completing this comprehensive study.

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1 INTRODUCTION

The City of Austin, Texas has been committed to building a comprehensive program of nonpoint source (NPS) pollution control since 1975. Based in part on the Nationwide Urban Runoff Project (NURP) study (Engineering Science and COA, 1983) recommendations, the City developed a stormwater monitoring and evaluation program specifically targeted at NPS pollution indicators. A variety of Best Management Practices (BMPs) have been monitored and evaluated by the City including wet ponds, filtration ponds, and detention ponds. In 1986, the City passed the Comprehensive Watersheds Ordinance or CWO (COA, 1986a) to control NPS pollution from all developing watersheds. This Ordinance requires a full range of BMPs including impervious cover limitations, buffer zones, protection of critical environmental features, limitation on disturbance of the natural stream, erosion control practices, and structural water quality controls. The City also conducts an ongoing public outreach and pollution prevention effort. However, controlling NPS pollution from urbanized watersheds is particularly difficult. Two primary BMPs used in the developing watersheds, impervious cover limitations and buffer zones, are typically not applicable in watersheds with extensive existing development. Structural BMPs are typically very costly since both construction and land costs are increased by the limited number and size of available sites.

The advisory board for the City's NURP study recommended that storm loads from high density commercial areas be quantified and that costs and benefits of various structural control measures be obtained. None of the City's previous NPS activities had addressed these recommendations with respect to retrofitting BMPs in existing high density urban watersheds. Therefore, in 1990, the City of Austin Environmental and Conservation Services Department applied for and obtained a $150,000 EPA Section 319 Nonpoint Source Management Program matching grant. The project included storm water monitoring, evaluation of structural BMPs, and non-structural BMP studies such as public education, citizen monitoring, and technology transfer. It is expected that these

BMP projects should improve the quality of stormwater runoff to the City's receiving water bodies in the highly developed watersheds.

The objectives of this grant study are to:

- Develop a storm water monitoring program for studying structural BMPs.
- Implement primary structural BMPs and evaluate the treatment or efficiency and cost effectiveness of such BMPs for urban NPS pollution control.
- Establish various non-structural BMP programs as a pilot study for source control of urban NPS pollution.
- Present the results and conclusions of this study to various communities as a technology transfer program.

2 SELECTION OF BMPs FOR IMPLEMENTATION AND EVALUATION

The COA has a long history of implementing BMPs for urban NPS pollution control. The City started its NPS pollution control program in the late 70's by establishing watershed regulation ordinances (COA, 1980). Based on these ordinances, the City requires the developer to submit drainage and water quality control plans as a part of the land development process. These plans specify structural and non-structural pollution control measures, such as buffer zones, limitation on impervious cover and cuts and fills, erosion and sedimentation control plans, and water quality control basins. Originally the water quality control basins consisted of a variety of structures including filtration basins, sedimentation ponds (or dry ponds), or a combination of detention and filtration basins.

The COA monitored six of these control basins between 1982 and 1988. Figures 1-2 show two of the six control basins. Both basins have no pre-treatment devices. The Barton Creek Square Mall pond was built within the flood control pond. The City improved this design at the Jollyville Road Pond. The improved design has a splitter box that diverts the first 1/2-inch of runoff to the sand filtration basin and releases the remaining discharges (overflowing a weir) to the floodwater detention. The City completed the BMP monitoring in 1988 and presented the results of the monitoring study in 1990 (COA, 1990a).

In 1986, the COA enacted the Comprehensive Watershed Ordinance (COA, 1986a) that consolidated several ordinances for individual watersheds. The CWO requires the implementation of sedimentation/filtration basin combinations for most land development projects in the Austin jurisdiction area except in the most highly urbanized watersheds. The COA expanded this requirement to the "Urban Watersheds" following the establishment of the Urban Watershed Ordinance (UWO) in 1991. In the meantime, the City staff has developed a technical manual for the design and implementation of sedimentation and filtration basins (COA, 1988a; updated 1994).

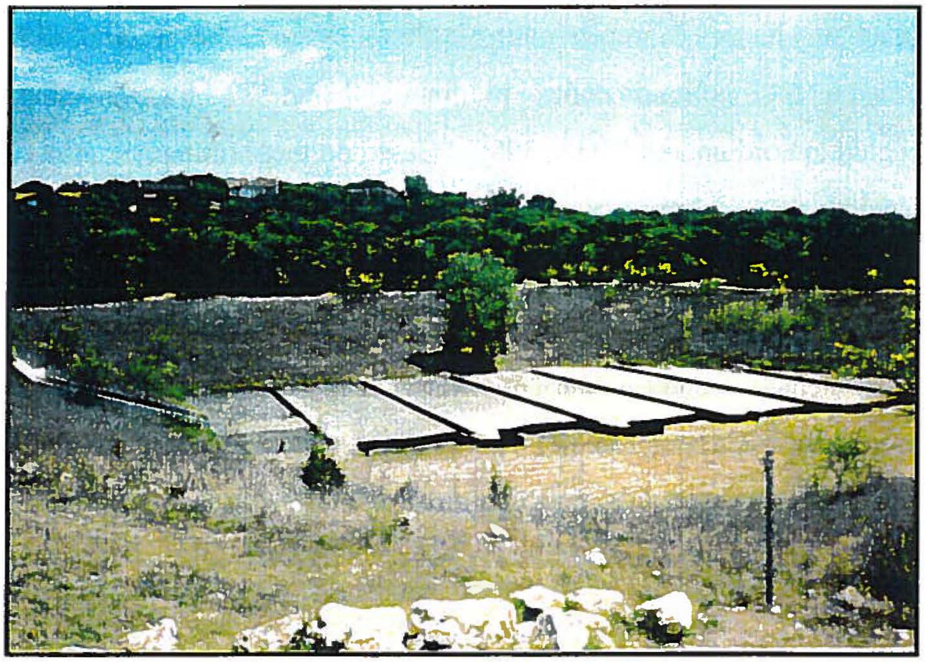


Figure 1. Early-stage sand filtration built inside a flood control detention basin.

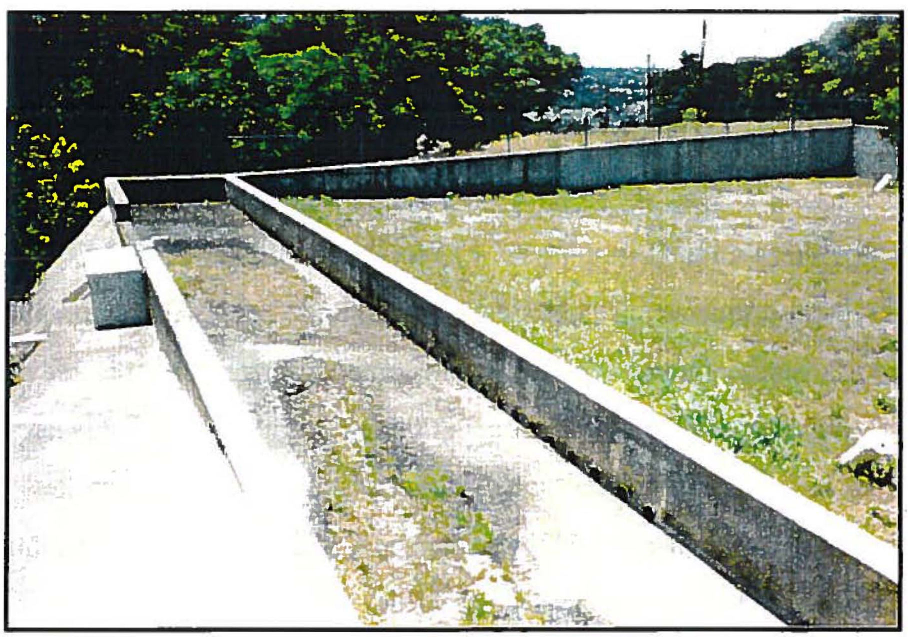


Figure 2. Improved sand filtration with runoff splitter that diverts runoff that exceeds the volume of the first 1/2" of runoff.

The manual specifies that a sand filtration basin should divert and treat at least 1/2-inch runoff from the contributing drainage area. It further provides criteria for the determination of dimensions for the pre-treatment device and sand filter. Each sand filter should have a partial or full sedimentation pond as a pre-treatment device. Figure 3 shows a sand filtration system at Barton Ridge Plaza. Figure 4 shows a full, pre-treatment sedimentation pond for the sand filtration.

The COA implemented its first wet pond in 1980 for the Nationwide Urban Runoff Project or NURP (Engineering Science and COA, 1983). The City closed the release gate at the Woodhollow Detention Pond to create a permanent pool for the pond. Figures 5-6 show the pond's permanent pool and the pipe outlets at the top of the permanent pool. The City tested the water quality control function of this pond during 1984-87.

This pond has a moderate removal efficiency even though the design of this pond does not comply with the standard design (Schueler, 1987) of a wet pond. The COA has since encouraged the implementation of wet ponds as an alternative to the sedimentation/ filtration basin for some development projects. In 1991, the COA established its Drainage Utility (DU). The DU business plan (COA, 1992) outlines the plan to retrofit the City's urban and suburban watersheds with water quality ponds. The creation of wet ponds within flood control ponds is a popular method for water quality retrofit in an urbanized watershed.

In the past five years the COA has implemented wet ponds of various design. These ponds includes those at Convention Center, Central Market, Far West Boulevard, and St. Elmo Service Center. The COA is or will be testing these ponds under different monitoring projects (COA, 1996a).

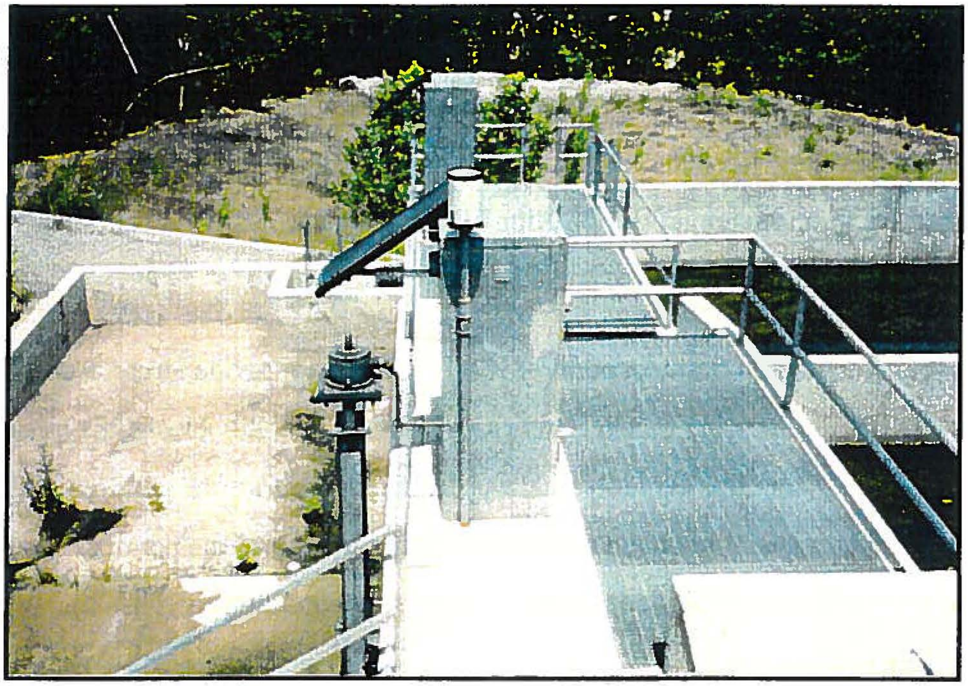


Figure 3. Sand filtration with sedimentation pre-treatment.

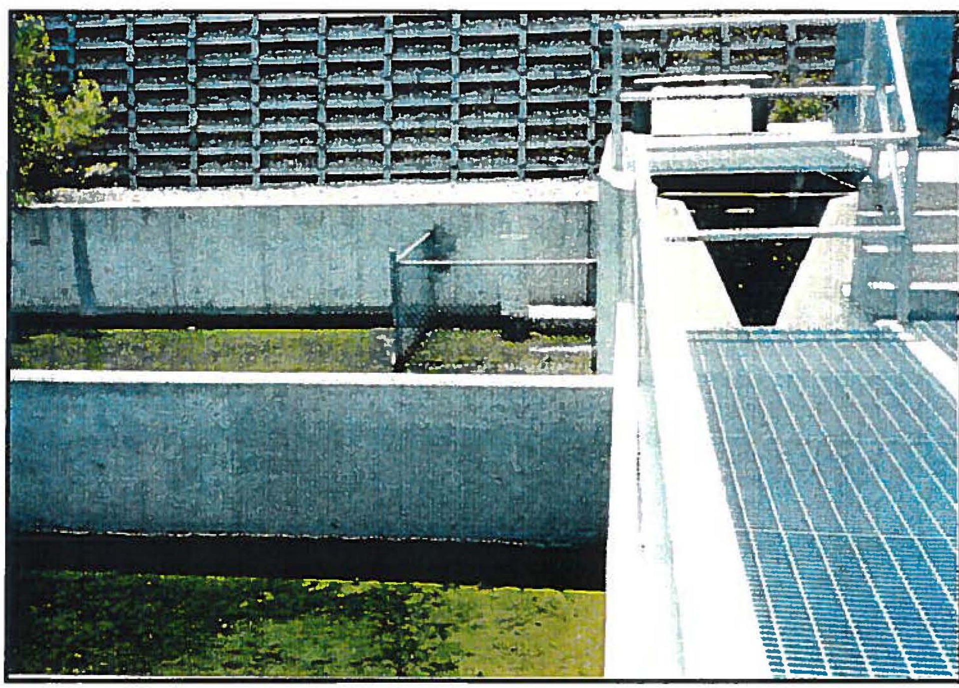


Figure 4. Sedimentation pond of the Barton Creek Plaza sand filtration system.

Figure 5. Permanent pool of the Woodhollow Detention Pond.

Figure 6. Outflow pipe openings of the Woodhollow Detention Pond at the permanent pool level.

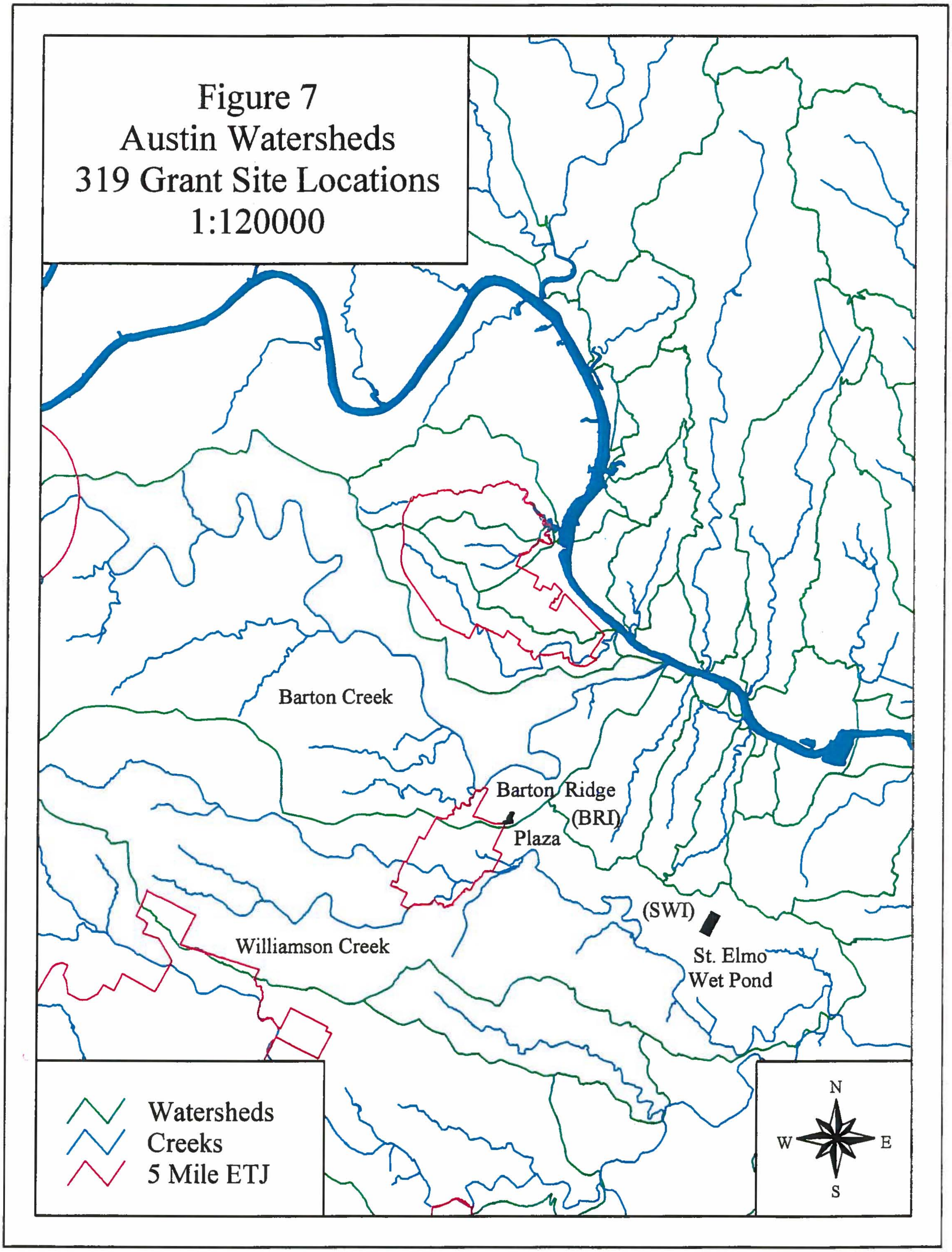
2.1 Treatment Controls

Two structural BMPs for retrofitting urbanized areas were demonstrated for this grant, a retrofitted wet detention pond at the St. Elmo service center in the Williamson Creek watershed, and a sedimentation /filtration pond at Barton Ridge Plaza in the Barton Creek watershed (Figure 7). Although these sites are not watersheds considered urban, the drainage areas of the ponds themselves represent accurately a typical retrofit situation. These two facilities both demonstrated state-of-the-art design of two basically different pollutant removal mechanisms. The design and construction of these two water quality control basins comply with the guidelines of the Environmental Criteria Manual which sets COA's Design Guidelines for Water Quality Control Basins and other studies (Schueler, 1987 and 1991). The data supplied in this report indicates that these basins are effective in controlling urban NPS pollution.

Both basins have been in operation since Spring 1993. The COA began to monitor the operations of Barton Ridge Plaza Ponds (BRP) in September 1993 and St. Elmo Wet Pond (SEP) in December 1994. The following paragraphs describe the implementation process of both basins.

2.1.1 The Design and Implementation of Barton Ridge Pond

In 1988, the COA entered a community facility agreement with the developer of Barton Ridge Plaza (Barton Ridge, Ltd.) to construct the sedimentation/filtration ponds. The City worked with the developer's engineers (Bury and Pittman, 1988) to ensure that the design and construction would comply with the COA's design criteria. The City desired to test this innovative design through a monitoring and assessment program, and has now done so for more than two years. The design, monitoring, and assessment of the BRP system constitutes one of the key elements of this grant project.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2.1.2 The Design and Implementation of St. Elmo Pond

The City has also selected St. Elmo Wet Pond (SEP) for analysis as part of this grant study. According to the nationwide criteria (Scheuler, 1987 and 1991) and the COA's findings concerning wet ponds, St. Elmo Wet Pond is a well designed retention structure for water quality control. To evaluate the removal efficiency of this control, the City has monitored the pond since April 1995. Like BRP, the design, monitoring, and assessment of SEP constitute another key element for this grant study. Figure 8 shows the major portion of SEP.

2.2 Source Controls

The City of Austin has made the control of nonpoint source (NPS) pollution a high municipal priority in response to citizen direction documented by referendum, council member directives, and customer surveys.

In order to combat this problem, the City has devised a multi-faceted program to reduce the level of NPS pollution entering the waterways within the City's jurisdiction. This grant, received in 1990, provided $28,000 for public education to further this goal. The City is committed to continuing development of educational materials to increase public awareness of NPS impacts and how every individual can reduce NPS pollution at its source. Development of educational materials and extensive public outreach was performed in-house throughout the grant.

The grant funds were used to initiate educational programs and outreach efforts on source controls which were continued after the grant. The City provided TNRCC with the developed education program and a schedule for its implementation. In keeping with the focus of the grant on urbanized watersheds, a significant portion of this effort was directed at reducing trash and debris in areas near built-out watersheds. Along with other goals, the public education effort also included an increased emphasis on integrated pest management (IPM), with the goal of pesticide use (and misuse) reductions. The grant

Figure 8. Panorama showing the major portions of the St. Elmo Wet Pond.

funds paid for IPM educational materials and information distributed through the existing City xeriscape program network.

This task also included implementing a citizen monitoring program for Waller Creek in order to increase public awareness, involvement, and support for control of urban NPS pollution. The City developed a citizen monitoring program which included field water quality sampling at three locations along Waller Creek near the headwater, mid-course, and mouth. These measurements were made on a quarterly basis for a year. The measurements were compared to an established citizen monitoring index developed for use by the City and implemented throughout the tributaries draining to Town Lake. In addition, three reports on the geology, flora, aquatic macrobenthos, and algae of Waller Creek were prepared by citizen paticipants. These reports were provided to TNRCC in October 1992, and results are summarized in a subsequent section of this report. An Austin Youth River Watch effort was also conducted with the COA staff assisting Mendez Middle School students in weekly field monitoring at the St. Elmo Pond.

Finally a survey of behavioral patterns and knowledge level of citizens in Austin, Texas with regard to urban nonpoint source pollution was completed in August of 1993. The report on this survey was also provided to the TNRCC in the 1993 Second Quarter report and will be summarized herein.

3 WATER QUALITY MONITORING AND ASSESSMENT PROGRAM

The monitoring and assessment program of Barton Ridge and St. Elmo Ponds (BRP and SEP) is an essential element for the grant study. It is also an important component for the current COA's Storm Water Monitoring Program - SWMPM (COA, 1996a). The COA has developed a long-term schedule (COA, 1990a and 1996a) for implementing its stormwater monitoring program to assess the functions of structural BMPs.

The COA staff designed the overall SWMPM in accordance with an experimental plan. The plan specifies the requirements to produce sufficient, statistically valid data for assessment and interpretation. For the monitoring of each site, there is a detailed working process that consists of elements such as site plans, flow measurement design, permitting, construction, instrumentation, sampling plan, monitoring operation, lab analysis, data processing, data analysis, and database development (COA, 1993a and 1993b). A quality assurance plan is associated with each element of the working process. The assessment program uses data collected from the SWMPM. The staff has developed statistical methods for assessing the NPS pollution, the effectiveness of structural BMPs, and the impacts of the pollution and BMPs on receiving water quality (COA, 1990b and 1995a).

3.1 The City of Austin Storm Water Monitoring Programs

The COA has had three comprehensive storm water monitoring programs since 1974. The in-stream storm water monitoring program is a cooperative project under a joint funding agreement between the COA and the U. S. Geological Survey (USGS). Based on a sampling plan specified jointly by both agencies each year, the USGS has continuously tested the storm water from large creek basins at 11 streamflow gauging stations since January 1975. The objective of this program is to evaluate the effects of urban development on streamflow water quality. In 1984, the COA expanded the NURP (ES and COA, 1983) monitoring project by establishing 16 additional monitoring stations. The program monitored storm water from nine small, single land-use watersheds, and tested six storm water quality control structures. The objectives of the program (COA, 1986b) were to evaluate the effects of land-use and structural BMPs on non-point source pollution in order to refine watershed ordinances on regulating land development projects. This monitoring study indicated that land-use is not the only factor impacting urban NPS pollution. It also points out that sand filtration and wet ponds can be effective control structures for controlling NPS pollution.

The COA started a new monitoring program in 1992 with the following objectives:

- Review and improve watershed rules that have been implemented in the recent years.
- Verify the effectiveness of some structural control measures that represent improved and/or innovative BMP design.
- Comply with the requirements of the EPA's National Pollutant Discharge Elimination System (NPDES) Municipal Storm Water Discharge Permit Program.
- Satisfy the requirements of EPA and TNRCC grant projects.

The EPA, Section 319 grant requires the evaluation of effectiveness of specific BMPs. The COA has selected BRP and SEP for the evaluation. The overall COA SWMPM provides additional data to characterize the selected BMPs.

3.2 The COA Storm Water Assessment Program

The COA's storm water assessment program uses statistical modeling and SWMM (Storm Water Management Model) to characterize NPS pollution and evaluate the impacts of this pollution and the use of structural controls on the water quality of receiving waters. The assessment program uses data collected from all COA storm water monitoring programs. The program has studied Barton Creek (COA, 1995b) and Waller Creek (COA, 1996b) basins using SWMM.

The City staff has also applied statistical methods to assess NPS pollution. This assessment (COA, 1995a) has developed equations to relate urban runoff pollutant concentration to watershed size and land development condition. The staff used watershed imperviousness and/or "Development Index" to characterize land development conditions. The "Development Index" identifies land-use, age and/or condition of infrastructures, and the degrees of traffic and housekeeping practice in the watershed. For example, the equation for estimating TSS concentration is

$$MC = b0\,(DA)^{b1} \qquad [1]$$

where MC is mean concentration (e.g., mean of event mean concentrations) in milligram per liter, DA is drainage area in acres, and b0 and b1 are regression coefficients. For other pollutant parameters studied,

$$MC = a0\,(DI)^{a1} \qquad [2]$$

where DI is "Development Index," and a0 and a1 are regression coefficients. The relationship between DI and watershed imperviousness is

$$PIC = 0.0515\,(DI)^{2.4003}, \quad \text{for } DI <= 3.50, \text{ and} \qquad [3]$$

$$PIC = 1, \quad \text{for } DI > 3.50,$$

where PIC is percent impervious cover. Then the mean concentration can be related to percent impervious cover by the following equation:

$$MC = a0\,(PIC/0.0515)^{0.4166\,(a1)} \qquad [4]$$

The percent impervious covers for the watersheds above BRP and SEP are 81% and 66%, respectively. The drainage areas for these two watersheds are 2.95 and 27.11 acres, respectively. Therefore, the mean concentrations for the watersheds can be estimated from the above equations. Appendix H0 (pages 1, 2, and 4, Appendix H0-1) provides the values of the regression coefficients (a0, a1, b0, and b1) and the comparisons of the predicted and observed mean concentrations for inflows at both BRP and SEP. The predictions of mean concentrations using the above equations are generally adequate in considering the high variability of runoff pollutant concentrations. The page 3 in Appendix H0 also presents mean concentration values for various land-use types for the Austin, Texas area. The concentration data can be better characterized by development conditions and watershed sizes, than by land-use types as specified in a previous study (COA, 1995a).

3.3 Stormwater Monitoring for Water Quality Control Ponds

Two important considerations when monitoring water quality control ponds are:

1) Obtaining an adequate number of paired inflow-outflow samples to ensure a statistically significant number of event mean concentration (EMC) values.
2) Ensuring that adequate sampling of flow and concentrations for the duration of individual storm events is conducted so that accurate estimates of EMC values can be made.

<u>Number of Paired EMCs:</u> An adequate number of paired inflow-outflow samples should be collected to ensure a statistically significant number of event mean concentration (EMC) values. Two important rainfall factors to consider are storm size and antecedent (dry period) conditions (COA, 1990b). The value of EMCs may vary with rainfall depth or antecedent condition in cases where one of the variables (depth or antecedent condition) changes while the other remains constant (COA, 1990c and Souer, et al., 1994). This finding is particularly true when the watershed impervious cover exceeds 40%, e.g., the EMC value for a 0.50" storm may be greater than that caused by a 1.50" storm (due to dilution of the runoff water), if the antecedent conditions are the same for both storms (e.g., 2 days). Likewise, the EMC value for a storm with an antecedent dry period of 20 days may be greater than that of a storm with a 2 day antecedent condition, if the storm size is the same for both storms (e.g., 0.50").

Assuming that EMC values may be significantly different between two different classes of storm size (small and large) and two classes of antecedent dry periods (short and long), it is recommended that a total of four (2x2) "class combinations" be defined. For each class combination, the number of EMCs recommended for a study is 4 to 6 in order to obtain an unbiased sample mean. Thus, the number of EMCs needed to characterize a watershed is 16-24 (4x4 and 4x6, respectively), at a minimum.

The number of EMC values needed to characterize the outflow from a water quality control pond will depend on whether the outflow samples are correlated to their paired inflow EMC values. If the outflow EMCs are not correlated, then the number of EMCs needed is 16-24, as described in the previous paragraph. If the outflow EMCs are correlated to inflow EMCs, then the number of EMCs needed can be less than 16. In this case, assuming that the data of paired EMCs is randomly distributed, the number of paired EMCs should be 6, at a minimum. Six pairs of EMC can provide a reasonable estimate of the sample mean or may be used for relationship fitting.

Estimating EMCs: Two important factors that effect the accuracy of EMC estimates are flow measurement from the drainage area and water quality sample collection during storm events.

When measuring flow to a water quality control pond, it is desirable to minimize the amount of ungaged areas above the monitoring station. Any unmeasured flow leakage or spillage should be avoided.

A sampling goal should be to collect samples over the entire hydrograph in order have valid EMCs. This can be very difficult, however, due to variations in hydrographs and equipment malfunctions. The COA staff has achieved good success by using a remote-control monitoring operation to collect samples. In this operation, staff observes runoff events from an office computer and directs the monitoring equipment to take discrete samples at appropriate points along the hydrograph. This discrete sampling yields a series of samples collected at intervals of equal flow volume (sometimes equal time intervals. It is often necessary to change the sampler's flow pacing (flow volume size interval) during a remote-controlled operation in order to sample over the entire hydrograph. These mid-event corrections negate the use of composite sampling as the adequacy of the sample aliquots will be distorted. Discrete samples are different from composite samples, the latter

3.4 Development of Watershed Data

The information on the watershed above a prospective monitoring station was used to design the station and to characterize water quality of inflows to a water quality control pond. The grant study team used GIS method to develop watershed data such as basin boundary, watershed ground cover, and distribution of storm sewer networks. The study applied ARC/INFO software (Version 3.4.2, ESRI, 1994) to develop information coverage in the proper format. The study further applied ARCVIEW software (Version 2, ESRI, 1994) to prepare watershed and drainage maps that contain all of the coverage.

The team obtained sewer network and street inlet location data from the site development plans submitted for permitting in the watershed and verified these data by field inspections. Watershed boundary and surface flow routing information was obtained through field inspections before and during runoff events.

The team collected ground cover information from a combination of three sources. The first source was the COA digital plannimetric coverage (1987 coverage). This coverage contained arcs, but not polygons. Arcs were connected and polygons formulated and labeled to provide ground cover coverage. The second source was site development plans. The relevant portions of these plans were digitized and used to update outdated portions of the plannimetric coverage. The third source was field inspection. Coverage were altered to reflect recent developments in the watersheds.

Ground cover information was combined with the watershed boundary coverage to compute ground cover percentages for each watershed. Ground cover was described as pervious or impervious areas rather than specific types of land coverage in order to simplify the analyses. Impervious cover percentages were then computed from the distribution of the ground cover.

3.5 Watershed and Pond Data for Barton Ridge Plaza Ponds

3.5.1 Watershed Data for Barton Ridge Plaza Ponds (BRP)

Barton Ridge Plaza is a commercial development (shopping center) located in the southwest area of Austin in the Barton Creek watershed, near the border of the Williamson Creek watershed. Retail businesses, and class rooms and offices of the Austin Community College are located in the plaza.

The BRP receives the drainage of rainfall runoff from a 2.95-acre portion of the parking area for Barton Ridge Plaza. The pavement area for the 2.95-acre area was first determined to be 2.2 acres or 76 percent. This estimate was further adjusted to a higher value of 81 percent by considering the parking spaces with lattice-type pervious pavers to be partially impervious. These squares are compacted aggregates, directly connected to the pavement in the parking lot. Figures 9-10 show the watershed and drainage to the BRP. Table 1 provides quantified data for these characteristics.

Table 1. Drainage Area and Impervious Cover for the Watershed above Barton Ridge Plaza Ponds

Description of Ground Cover	Area Acres	Area Percent	Pervious Percent	Impervious Percent
Grass	0.47	15.78	15.78	0.00
Asphalt Roadway	1.64	55.49	0.00	55.49
Lattice Parking	0.57	19.27	2.80	16.46
Sidewalk	0.18	6.18	0.00	6.18
Curb	0.10	3.29	0.00	3.29
Total	2.95	100.00	18.58	81.42

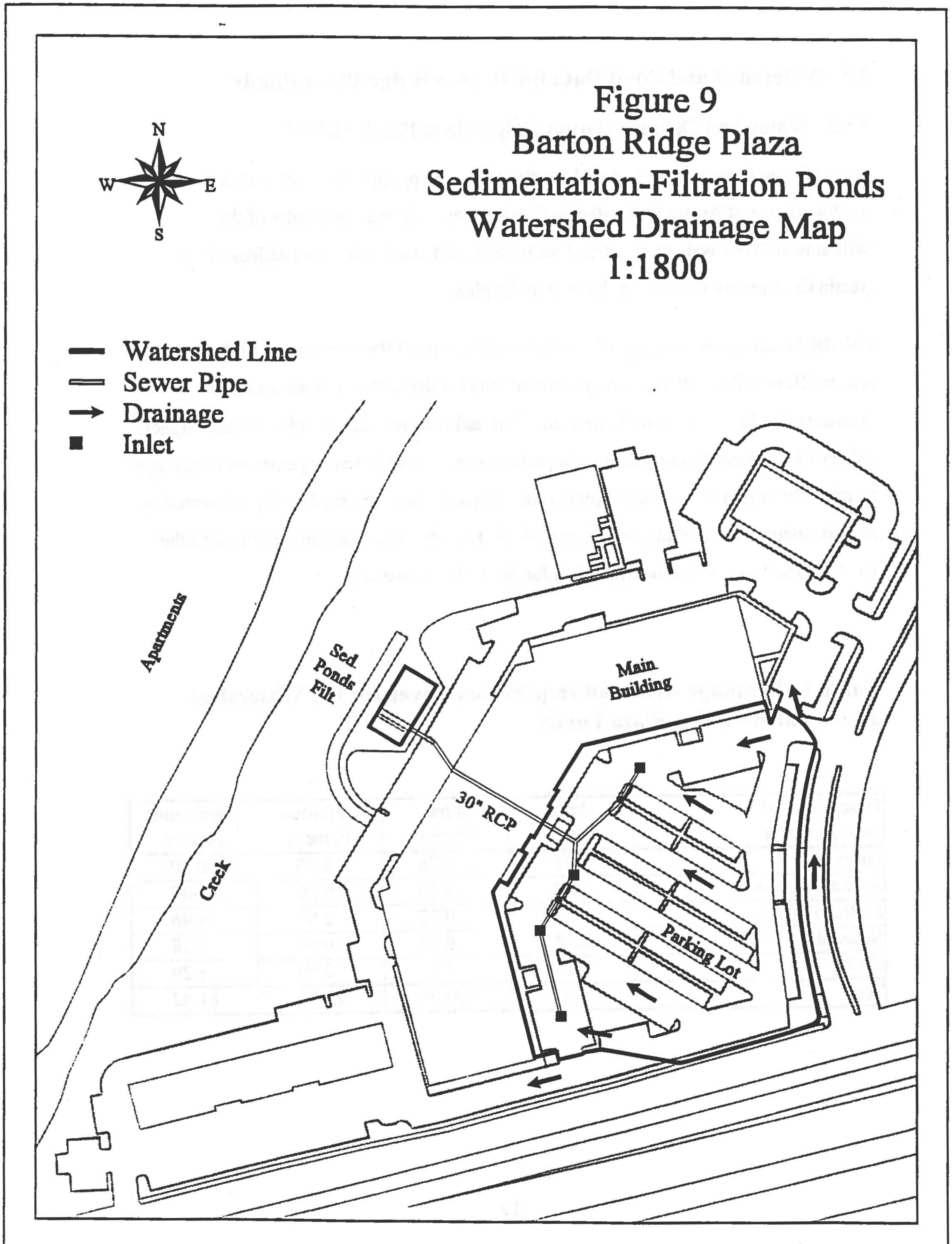
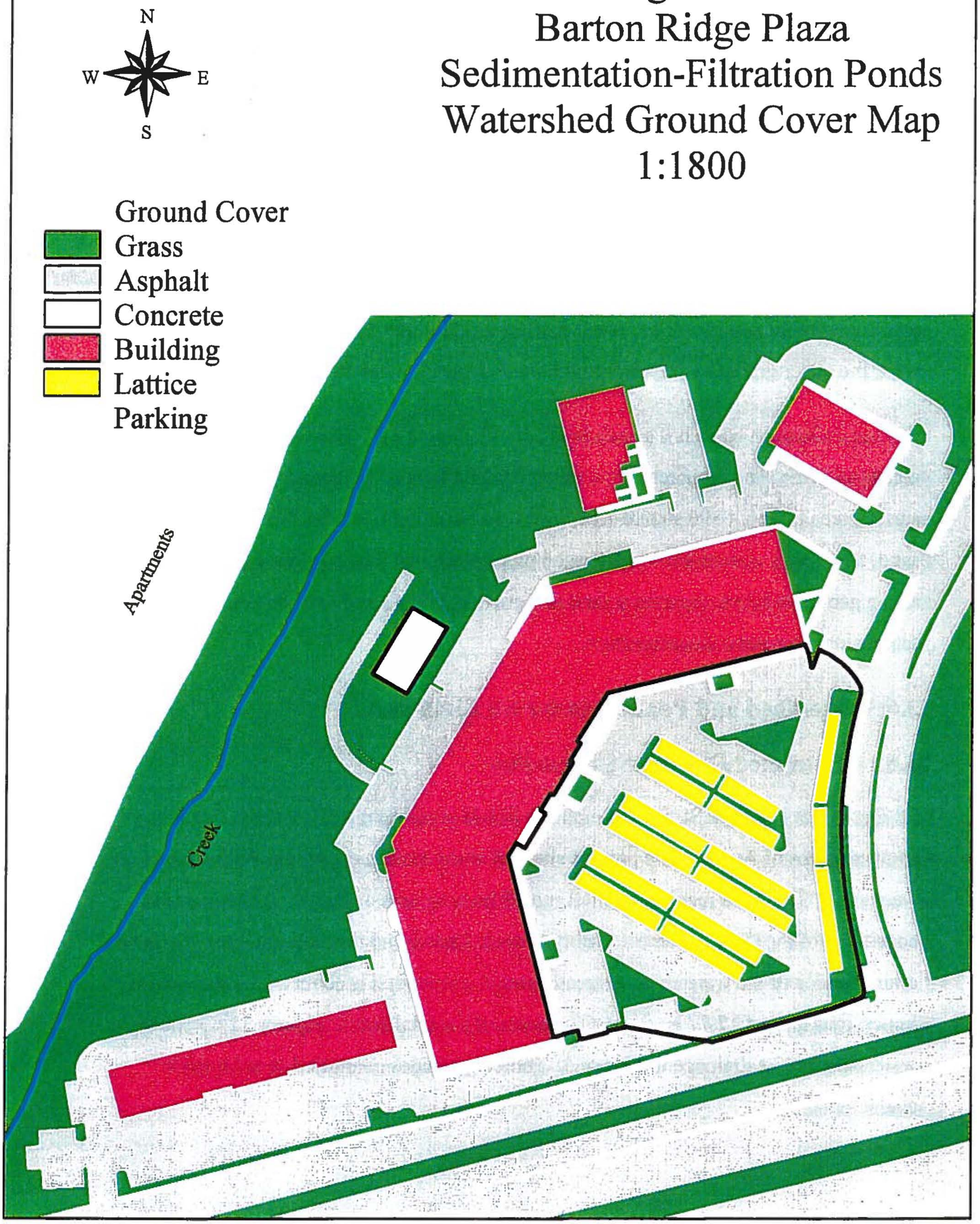


Figure 9
Barton Ridge Plaza
Sedimentation-Filtration Ponds
Watershed Drainage Map
1:1800

Figure 10
Barton Ridge Plaza
Sedimentation-Filtration Ponds
Watershed Ground Cover Map
1:1800



3.5.2 Pond Data for Barton Ridge Plaza Ponds

BRP ponds consist of a sedimentation pond, a sand filtration basin, and a channel or splitter box which diverts the first 2/3-inch (approximately) runoff into sedimentation and allows the remaining portion of runoff to overflow through a side weir. Figure 11 is a sketch of the BRP ponds that shows the relative locations of pond elements and monitoring locations.

The sedimentation pond can store approximately 7,000 cubic-feet of water (or about 2/3 inch runoff from the drainage area). There is a 35-foot long baffle wall to extend the path of runoff water before the water reaches a perforated 18-inch pipe riser. At the riser, the water gradually passes through the holes and falls into the sand filtration basin.

The sand filtration basin has a storage capacity of about 1,400 cubic-feet. The sand bed consists of fine sand (concrete sand, about 0.02-0.04 inch in diameter). The bed has a surface area of about 390 square-feet. The thickness of the bed is 18-inches. Below the sand, there is an underdrain of perforated pipes surrounded by a layer of gravel. There is also a geotexile fabric separating sand and gravel. Table 2 provides data of pond dimensions and pond characteristics.

3.6 Watershed and Pond Data for St. Elmo Pond

3.6.1 Watershed Data for St. Elmo Pond

St. Elmo Wet Pond (or St. Elmo Retention Pond) is adjacent to Meinardus Drive in the southeast area of Austin. The pond is situated at the eastern end of the Williamson Creek watershed. The pond receives rainfall runoff from an area of industrial development consisting of the COA's Electric Utility Service Center and the adjacent street. The total drainage area of the watershed upstream from the wet pond is about 27.11 acres, with an impervious area of 17.77 acres (or 66 percent of the total area). Figures 12-13 show the watershed and its drainage to the pond. Table 3 provides quantified data for these characteristics.

Table 2. Dimensions of Ponds and Related Data for Barton Ridge Plaza Ponds

Description	Dimension
Drainage Area (Acres)	2.95
Water Quality Volume (WQV, Inch)	0.65
Volume of Sedimentation Pond (WQV, Cubic-Feet)	7,000.00
Length of Sedimentation Pond (Feet)	56.00
Width of Sedimentation Pond (Feet)	41.67
Length of Baffle Wall (Feet)	34.50
Sand Bed Area (Square-Feet)	390.00
Ratio of Sand Bed Area to Drainage Area	0.003
Volume above Sand Bed Including Concrete Area (Cubit-Feet)	1,400.00
Distance between Sand Bed and Top of Retaining Wall (Feet)	3.00
Thickness of Sand Bed (Inches)	18.00
Type of Sand: Fine Sand/Concrete Sand, Diameter (Inch)	0.02-0.04
Type of Underdrain: Perforated PVC Pipe Riser	
Diameter of Underdrain Pipes (Inches)	6.00
Type of Drain at Sedimentation: Perforated PVC Pipe Riser	
Diameter of Riser (Inches)	18.00
Diameter of Holes on Riser (Inch)	0.50

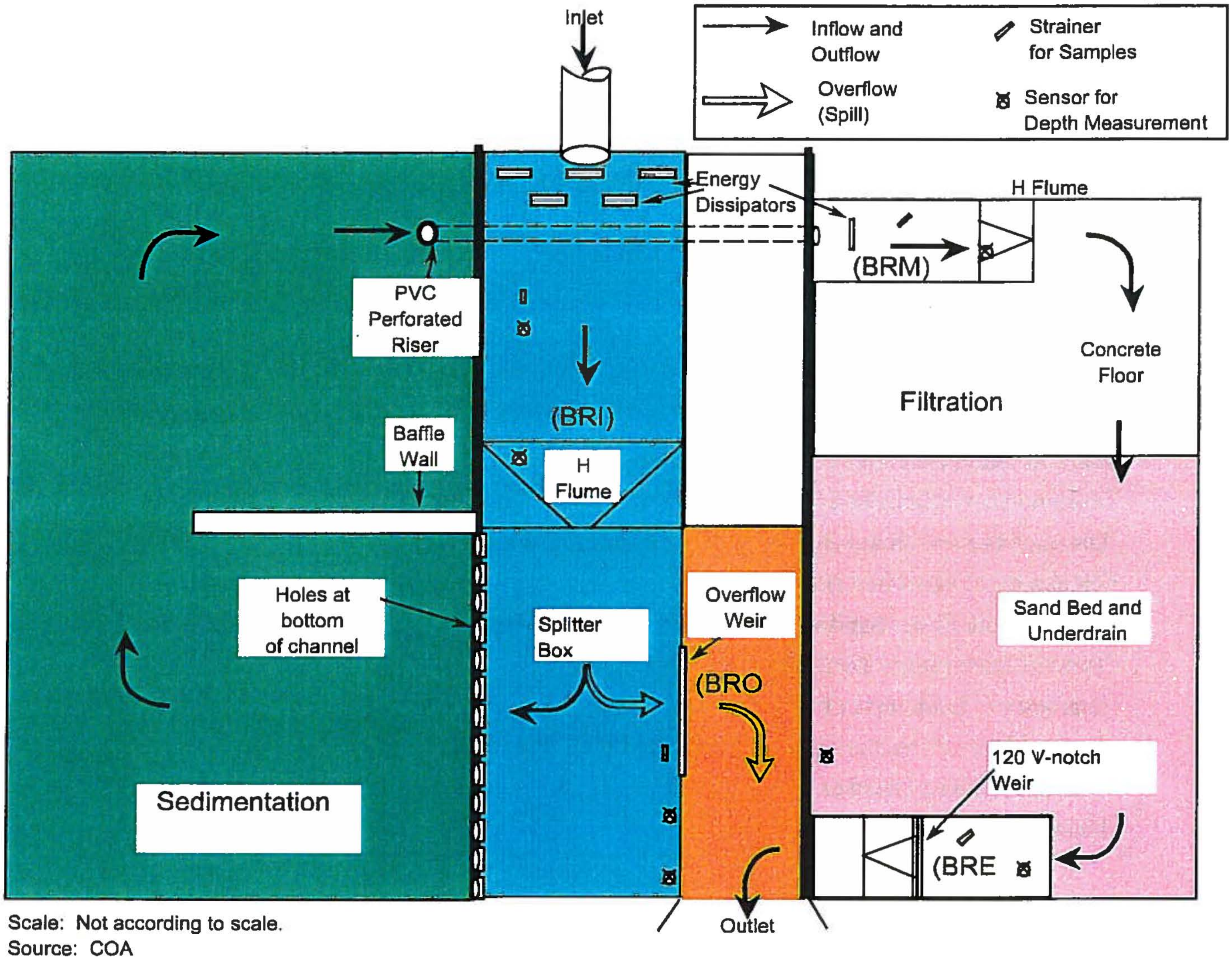


Figure 11. Plan view of ponds and monitoring stations at Barton Ridge Plaza.

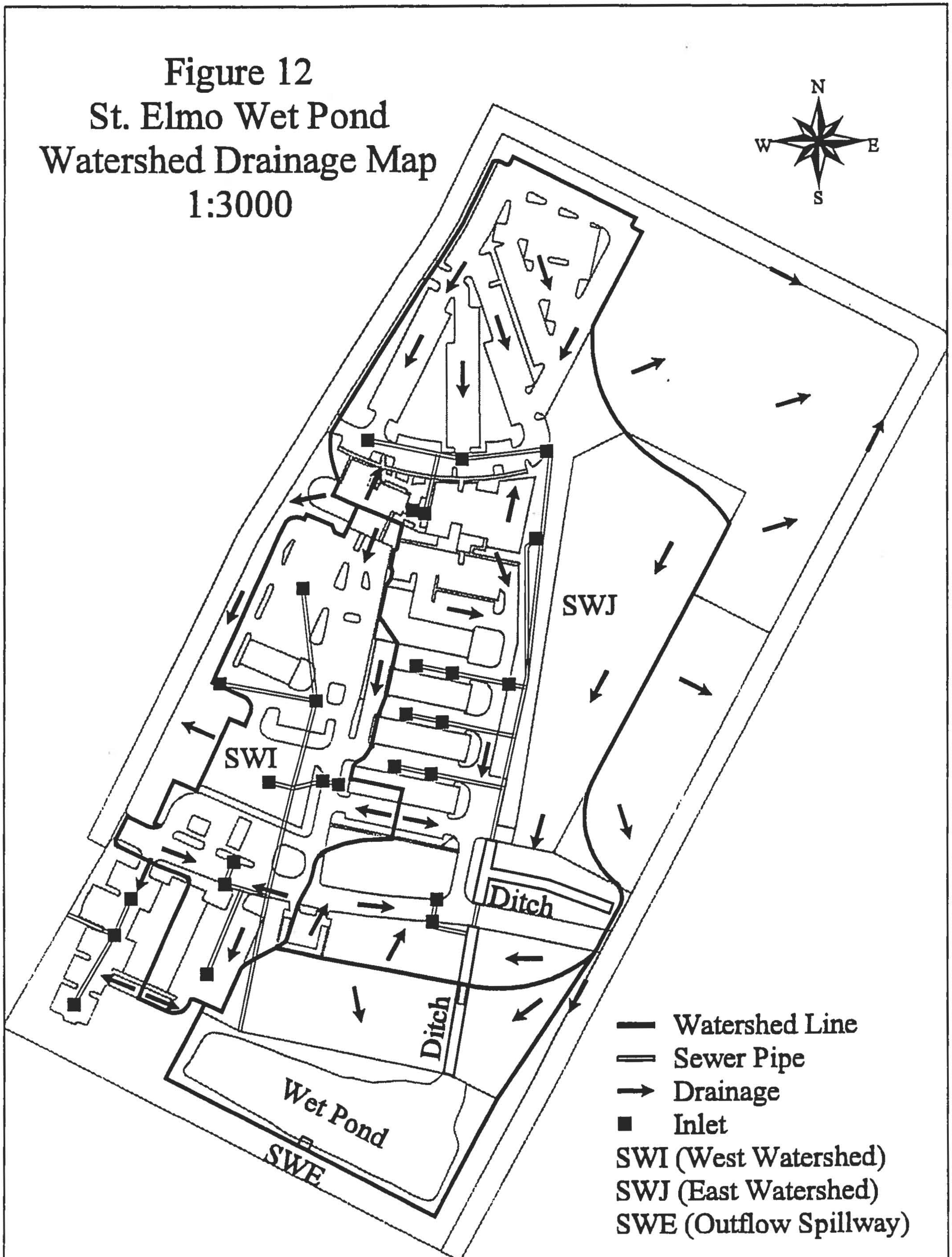


Figure 12
St. Elmo Wet Pond
Watershed Drainage Map
1:3000
N
W
E
S
SWJ
SWI
Ditch
Ditch
Wet Pond
SWE
Watershed Line
Sewer Pipe
Drainage
Inlet
SWI (West Watershed)
SWJ (East Watershed)
SWE (Outflow Spillway)

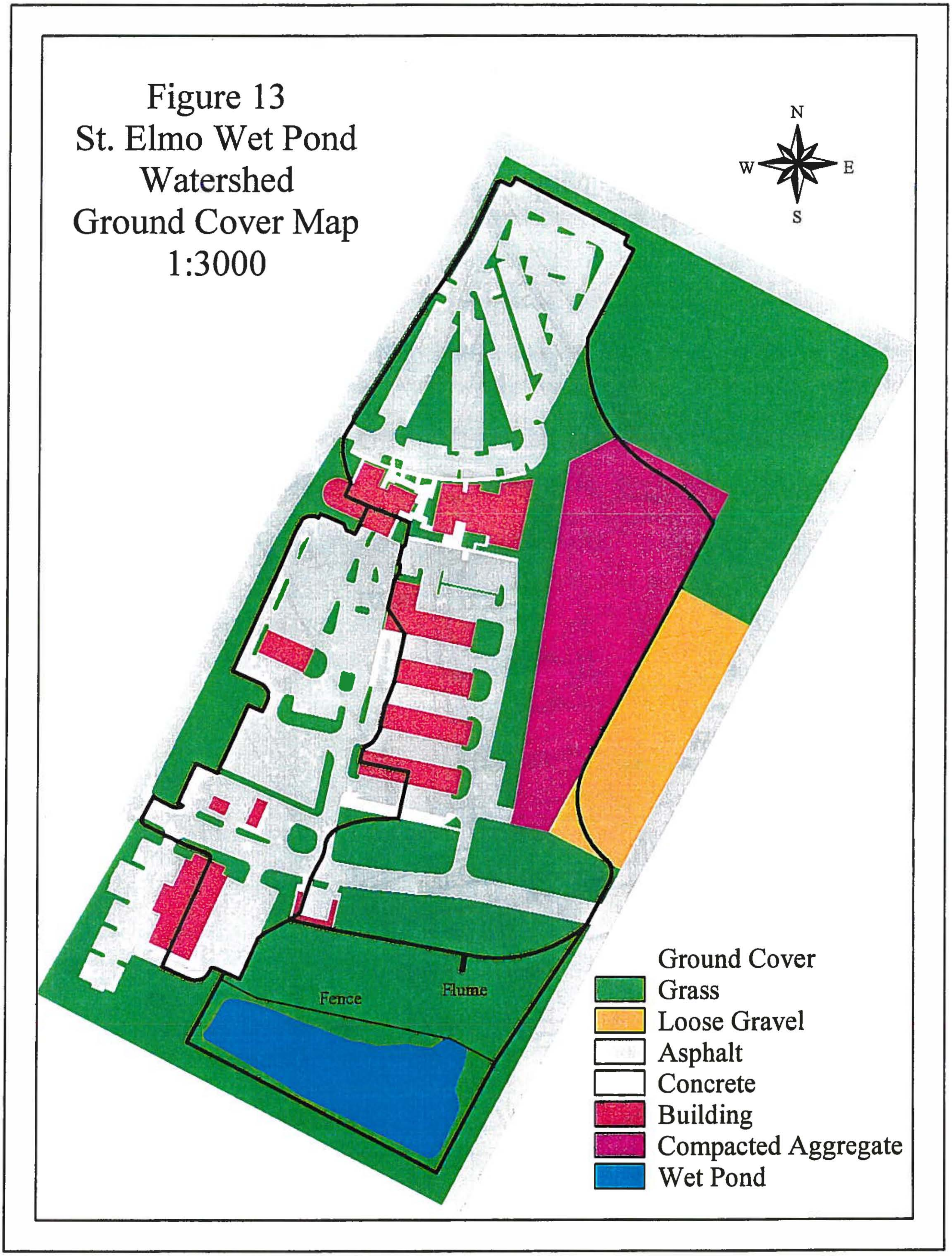


Figure 13
St. Elmo Wet Pond
Watershed
Ground Cover Map
1:3000

Table 3. Drainage Area and Impervious Cover for the Watersheds above St. Elmo Wet Pond.

Ground Cover (in Acres)	East WS (SWI)	West WS (SWJ)	Intervening Area	Total Area (SWE)
Roadway	5.84	4.20	0.00	10.03
Grass	5.20	0.94	3.07	9.21
Building	1.47	0.54	0.00	2.01
Compacted Aggregate	3.49	0.00	0.00	3.49
Loose Gravel	0.13	0.00	0.00	0.13
Sidewalk	0.29	0.14	0.00	0.43
Pond	0.00	0.00	1.80	1.80
Flume	0.00	0.00	0.01	0.01
Total Drainage Area	16.41	5.82	4.88	27.11
Impervious Cover (in Acres)	**East WS (SWI)**	**West WS (SWJ)**	**Intervening Area**	**Total Area (SWE)**
Pervious	5.33	0.94	3.07	9.34
Impervious	11.08	4.88	1.81	17.77
Total Drainage Area	16.41	5.82	4.88	27.11
Ground Cover (in Percent)	**East WS (SWI)**	**West WS (SWJ)**	**Intervening Area**	**Total Area (SWE)**
Roadway	35.57	72.10	0.00	37.00
Grass	31.69	16.16	62.93	33.98
Building	8.95	9.29	0.00	7.41
Compacted Aggregate	21.26	0.00	0.00	12.87
Loose Gravel	0.79	0.00	0.00	0.48
Sidewalk	1.74	2.45	0.00	1.58
Pond	0.00	0.00	36.87	6.64
Flume	0.00	0.00	0.20	0.04
Total	100.00	100.00	100.00	100.00
Impervious Cover (in Percent)	**East WS (SWI)**	**West WS (SWJ)**	**Intervening Area**	**Total Area (SWE)**
Pervious	32.48	16.16	62.93	34.46
Impervious	67.52	83.84	37.07	65.54
Total	100.00	100.00	100.00	100.00

This study divides this watershed into three portions. The drainage areas above the COA's storm water monitoring stations at the east and west sides are 16.41 and 5.82 acres, respectively. The impervious cover within these areas are about 11.08 (or 68 percent) and 4.88 (or 84 percent) acres, respectively. The remaining or intervening drainage area is about 4.88 acres, including a grass area and the pond itself.

3.6.2 Pond Data for St. Elmo Pond

St. Elmo Wet Pond was designed for both flood and water quality controls. The pond has a permanent pool or normal operating capacity of about 4.1 acre-feet of water. Above this capacity, the water flows out through a compound weir that consists of an 8-foot long steel plate and a 90-degree V-notch on the plate. The City staff has slightly lowered the level of permanent pool by establishing the compound weir at the outflow structure (the service spillway). The pond also has an earth-cut emergency spillway at the west end of the pond. At the top of the permanent pool, the water surface area is about 1.65 acres. The water level of the pond cannot always be maintained at the top of the permanent pool because of evaporation during dry periods. Table 4 exhibits the relationships of elevation, storage, and water surface area for the pond.

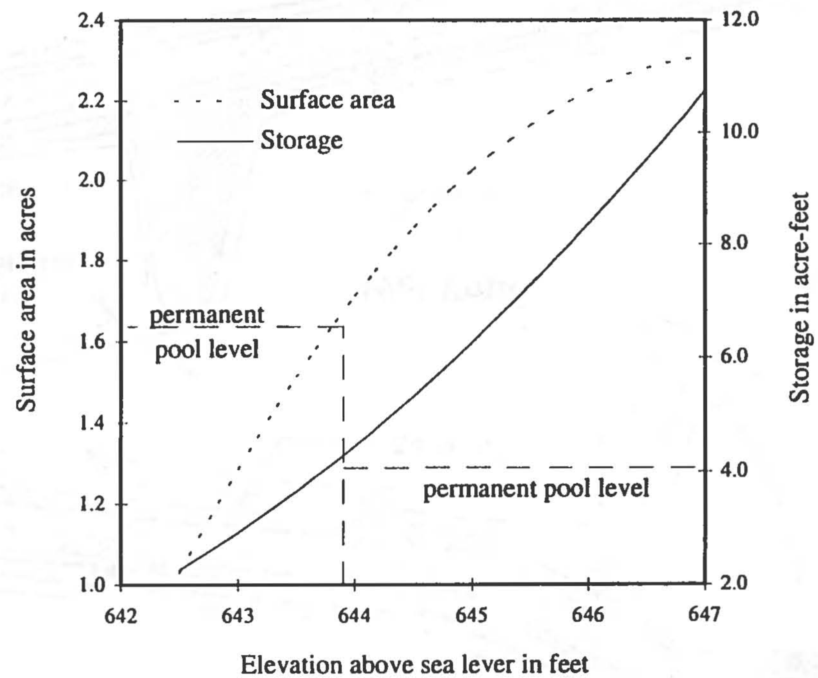
The COA designed a landscape and irrigation system for the pond in order to beautify the area and to enhance the water quality benefits. Vegetation in the pond will take up pollutants such as nitrate and nitrite and enhance the retention of solids. The landscaping divides the pond into four zones.

Zone A is the upland area. This is about 0.66 acres that contains grasses and native forbs. Zone B is at the waters' edge and has an area of about 0.13 acre. This area has plants that are suitable to the fluctuation of water levels. Zone C is about 0.45 acre within the shallow-water area. This area has marsh plants that can survive in waters of a depth of 6 to 18-inches. Zone D is about 1-acre in the deep water area. This area contains leafed aquatics and submergent species. Figures 14-15 show the plan, profile, and its 4-Zones of the pond area. Appendix I is a wetlands information booklet which details landscape design and installation information for St. Elmo Pond including specific plant species by

Table 4

Relationships of surface area, storage, and elevation for St. Elmo Wet Pond

Elevation (Feet)	Storage (Acre-Feet)	Surface Area (Acres)
642.50	2.26	1.03
642.67	2.47	1.12
642.83	2.69	1.20
643.00	2.92	1.28
643.17	3.15	1.36
643.33	3.40	1.44
643.50	3.65	1.51
643.67	3.91	1.58
643.83	4.17	1.65
644.00	4.45	1.71
644.17	4.73	1.77
644.33	5.02	1.83
644.50	5.32	1.88
644.67	5.62	1.93
644.83	5.94	1.98
645.00	6.26	2.02
645.17	6.59	2.07
645.33	6.93	2.10
645.50	7.27	2.14
645.67	7.62	2.17
645.83	7.98	2.20
646.00	8.35	2.22
646.17	8.73	2.25
646.33	9.12	2.27
646.50	9.51	2.28
646.67	9.91	2.29
646.83	10.32	2.30
647.00	10.73	2.31



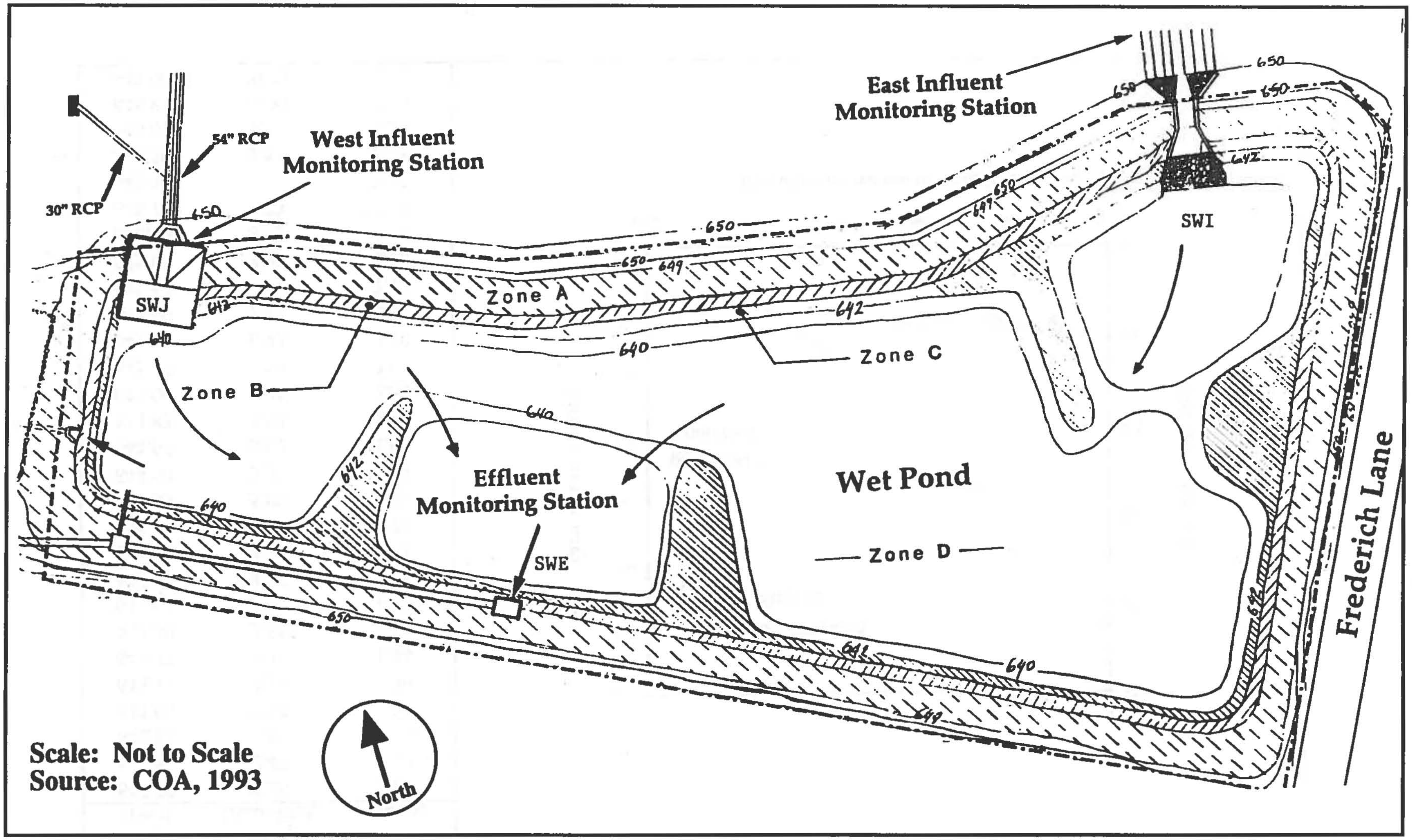


Figure 14. Plan view of the St. Elmo Wet Pond

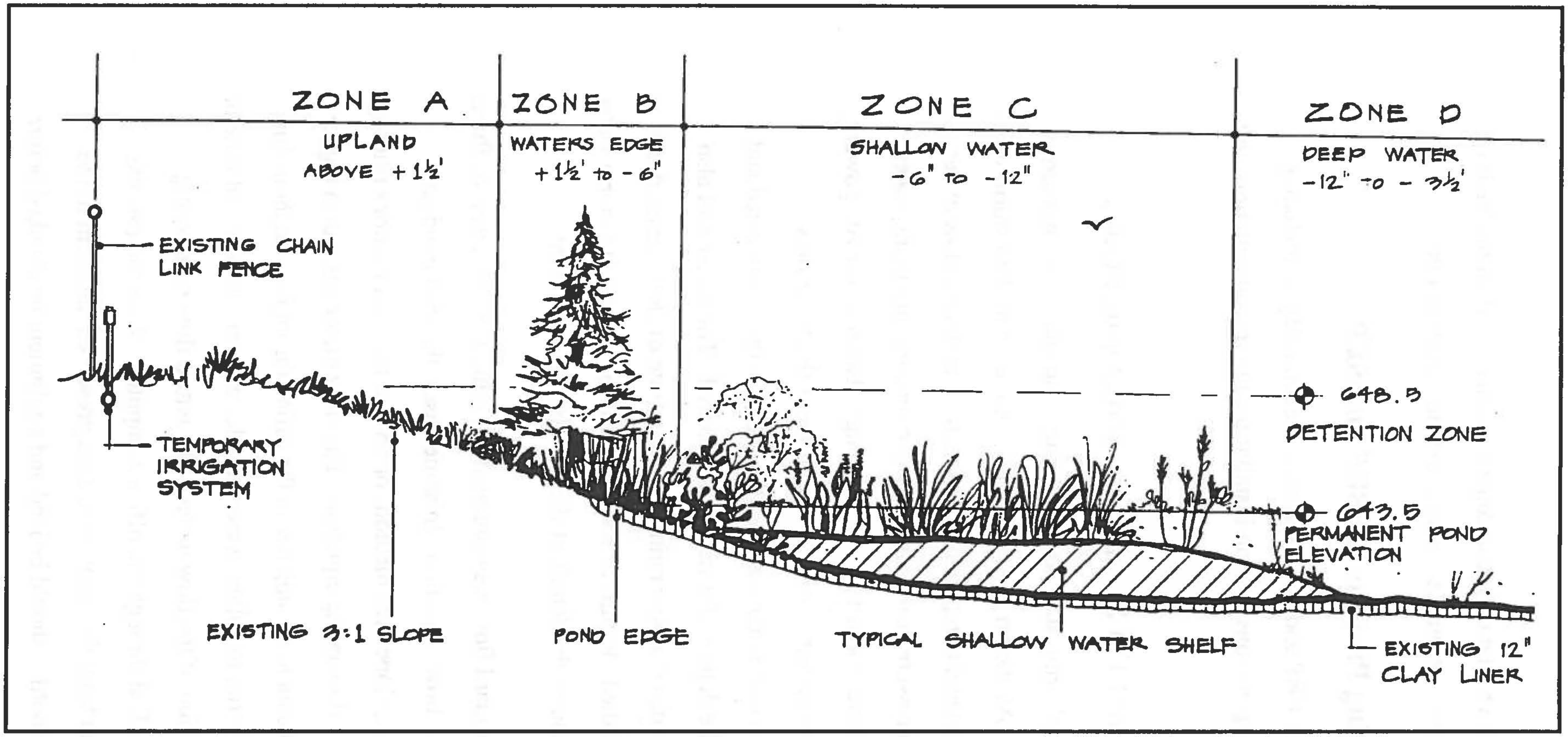


Figure 15. Profile of the St. Elmo Wet Pond (including landscaping zones).

zone. Naturally, the established vegetation will change seasonally and on the basis of flow and temperature fluctuations over time to reach a dynamic equilibrium.

3.7 Stormwater Monitoring Projects for BRP and SEP

The grant funded monitoring for BRP and SEP consists of several stages, including design of storm water monitoring stations, station installation and instrumentation, and monitoring operation.

3.7.1 General Description of COA Storm Water Monitoring Station

All of the COA storm water monitoring stations are remote-controlled flow measuring and sample collection systems. As shown in Figure 16, a remote-controlled storm water monitoring system consists of several components such as flow meter(s), flow meter sensing device (bubbler tubes, pressure probe, or ultrasonic sensor), automatic water quality sampler(s), hose and strainer for sampling, rain gauge, batteries (or AC power), solar panel (when needed), alarm system (optional), equipment shelter, a flow measurement structure, and an access to the station. The flow meter is connected and tripped by its sensor to record the depths of water in the channel. The meter will also convert depth readings to flow rates if a flow rating equation (rate of flow versus depth of flow relationship) can be established. Figure 17 shows the outlook of a COA storm water monitoring station. Figure 18 shows the details of the monitoring equipment.

The COA typically installs a standard flow measurement structure such as a weir or flume with an established "level versus flow" equation. In some cases, the staff conducts hydraulics modeling studies (e.g., slope-area method) or on-site flow calibrations (during storm rainfall events) to derive a flow rating equation. The flow meter has a data logger which stores and transmits flow data to a computer in the office through a telephone line. The water quality sampler can be run to collect water samples at intervals of equal time or flow volumes through the operation of the flow meter. The entire flow monitoring operation can be remotely controlled through the office computer. Nevertheless, the water samples must be picked up from the monitoring site, preserved, and sent to the laboratory for analysis. Sample bottles should be iced and equipment be checked before

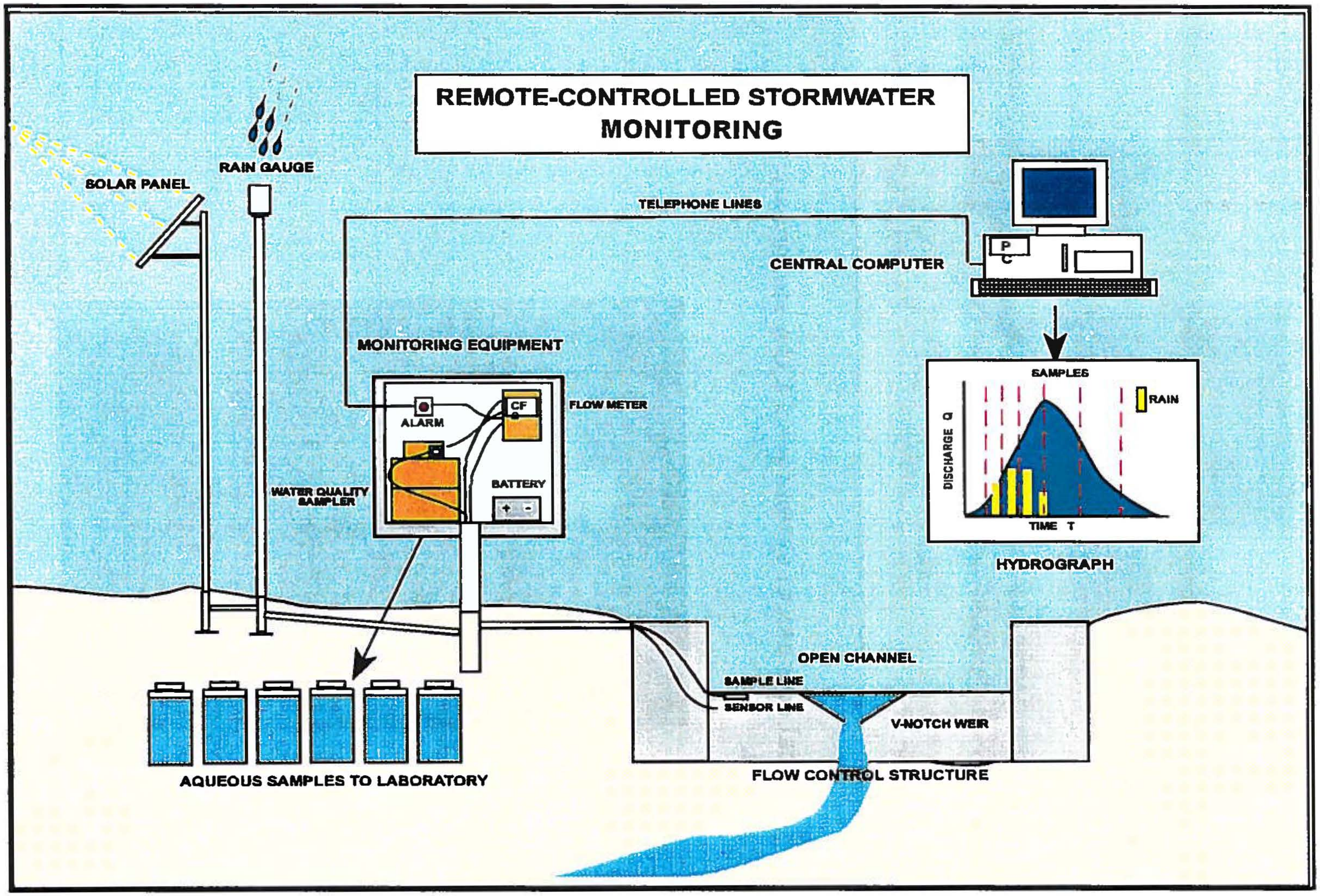


Figure 16. The COA remote-controlled stormwater monitoring operation system.

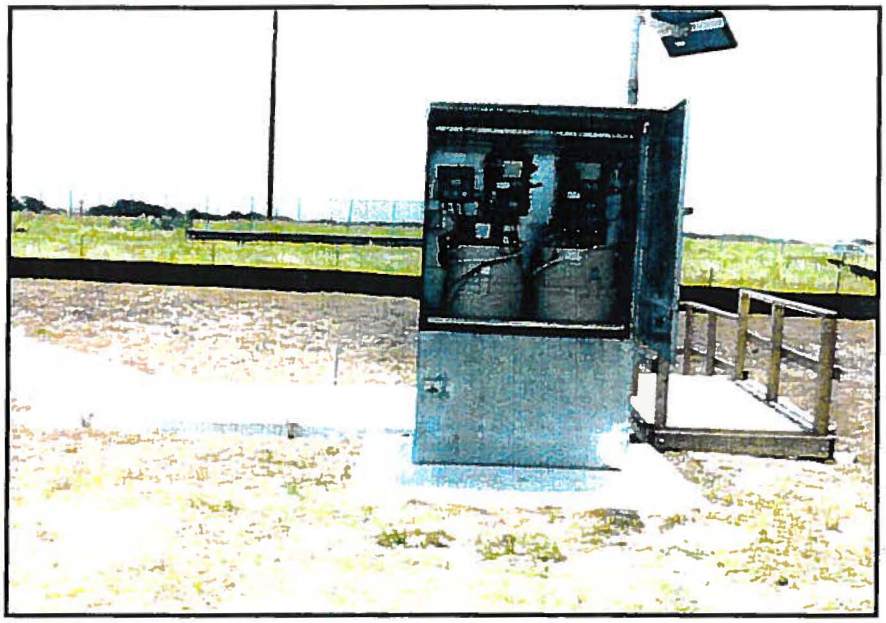


Figure 17. A typical equipment system for a COA stormwater monitoring station.

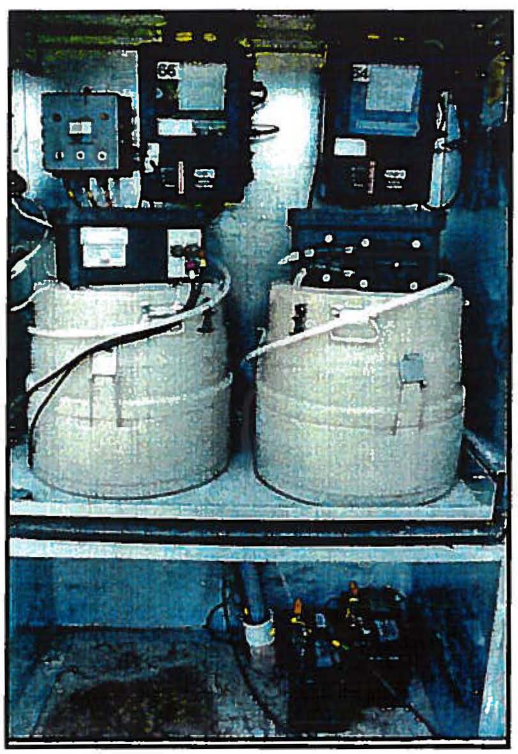


Figure 18. The essential elements of a monitoring equipment system.

an expected rainfall event. Equipment and flow measurement area should also be maintained periodically.

3.7.2 Storm Water Monitoring Design for BRP and SEP

Design for Flow Measurement: The following description specifies the design of flow measurement for this grant study.

- The grant study team first conducted field inspections to find an ideal location for establishing monitoring stations. A location that receives most of the drainage into the BMP is a good site. The location is ideal if the approaching pipe or channel toward this location is straight and primatic, and has a mild slope.
- Data on drainage areas and percent impervious covers of the watersheds above the inflow monitoring stations were collected, Tables 1 and 3 list these data.
- Based on a hydrologic model (e.g., Rational Method - COA, 1988b) and rainfall data, the runoff hydrograph for the watersheds was derived for a 2-year rainfall storm. The team further selected flow measurement structures that can measure the rate of flows up to a value equivalent to 80 percent of the peak flow rate of runoff from the 2-year rainfall storm..
- The team finally selected a flow measurement structure that is able to:
  - ⇒ measure the flows up to a discharge value as defined above,
  - ⇒ measure flows under backwater conditions that can occur due to the rise of water in the wet pond, and
  - ⇒ provide reasonably accurate measurements on water depths of low flows, such as the water depths of 0.05 to 0.25 inch.
- For outflow measurements, the team selected the flow measurement structures by estimating the average pond draw-down time and the volume of runoff from a rainfall event that represents average annual rainfall condition (an event of about 0.75 to1.10-inches of rainfall; about 50% of the annual rainfall amount generated from rainfall events equal or less than this size). A structure was selected that can adequately measure the depths of flows and can pass the entire outflows within the pond's average draw-down time.

Sampling Plan: The sampling plan consists of the following components:

- **Sampling Period:** The COA staff assumed that the treatment efficiency of a pond may vary with the conditions of inflows to the pond. In this case, the monitoring would test the inflows of different storm sizes and different antecedent conditions. The COA planned to monitor both ponds for 2-3 years for about 16-24 runoff events. The monitoring is continuous in order to collect data that can reflect the normal annual runoff conditions. The planned sampling periods for BRP and SEP were 1993-96 and 1995-96, respectively. The sampling period for SEP for the grant study, however, is about eight months in 1995, because of a late selection of the pond in the revised work plan.

- **Sampling method:** The grant team conducted sampling for the two ponds through remote-controlled operation. Following the operation of a flow meter, the sampler collects a water sample at the end of a pre-set interval of volume of flow. The staff collects a set of grab or discrete samples, instead of one composite sample, in order to change "flow pacing" during the runoff event. As described above, it is difficult to obtain paired inflow-outflow EMCs through the collection of composite samples.

Pollutant Parameters: This study analyzes water samples and tests twelve parameters for the conventional pollutants and four parameters for the heavy metals. These pollutant parameters are:

Total suspended solids (TSS), 5-day biochemical oxygen demand (BOD), chemical oxygen demand (COD), total organic carbon (TOC), total kjeldahl nitrogen (TKN), nitrite and nitrate (NO2+NO3 as N), ammonia (NH3, as N), total nitrogen (TN), total phosphorous (TP), dissolved phosphorous (DP), fecal coliform (Fe. Col.), fecal streptococci (fecal Strp), total cadmium (Cd), total copper (Cu), total lead (Pb), and total zinc (Zn).

3.7.3 Monitoring Stations for BRP and SEP

Monitoring Stations for Barton Ridge Plaza Ponds: There are four storm water monitoring stations established at the Barton Ridge Plaza Ponds (Figures 19-20). The grant study team coordinated the design and implementation of flow measurement structures during the process of the pond construction. Some modifications were required to ensure adequate flow measurement. At the inflow station, the flow measurement structure is a 3-foot H-flume. The approaching channel to the structure is 5 feet wide and about 15 feet long measured from the end of a 30-inch drain pipe. The team installed two ISCO flow meters and one sampler (ISCO, 1990) at this station. In addition, the staff successively calibrated the flow using velocity and area-velocity meters (ADS, 1993; American Sigma, 1995). The flow passing through the structure was mostly laminar under subcritical flow conditions. The measurements of flow depths are generally accurate. Figure 21 shows the H-flume at the inflow station (viewed from the downstream side).

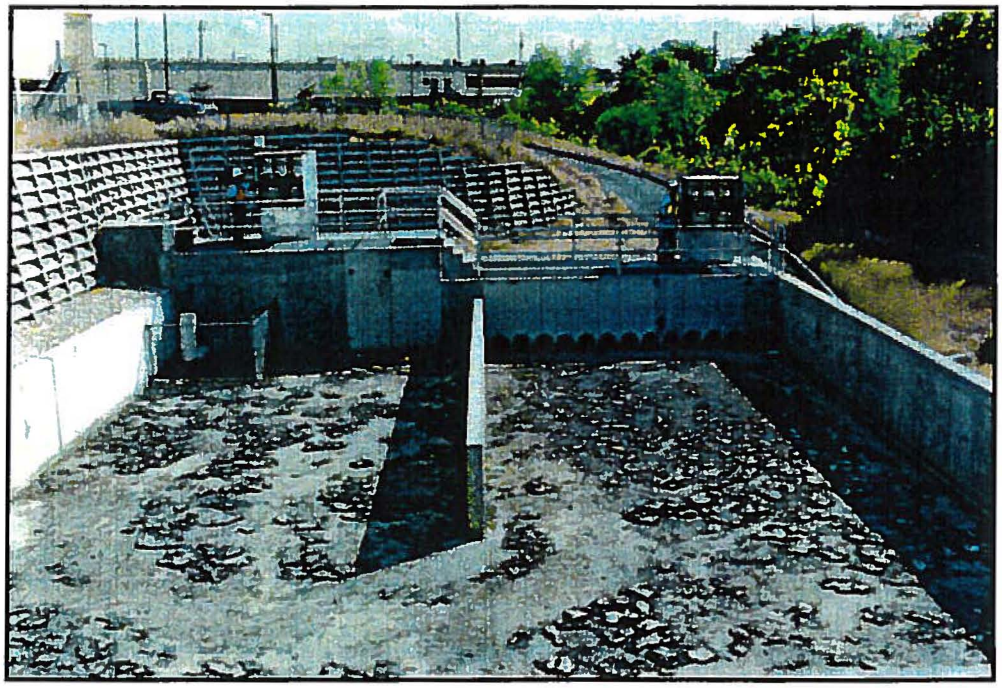


Figure 19. Stormwater monitoring station at Barton Ridge Plaza, viewed from sedimentation side.

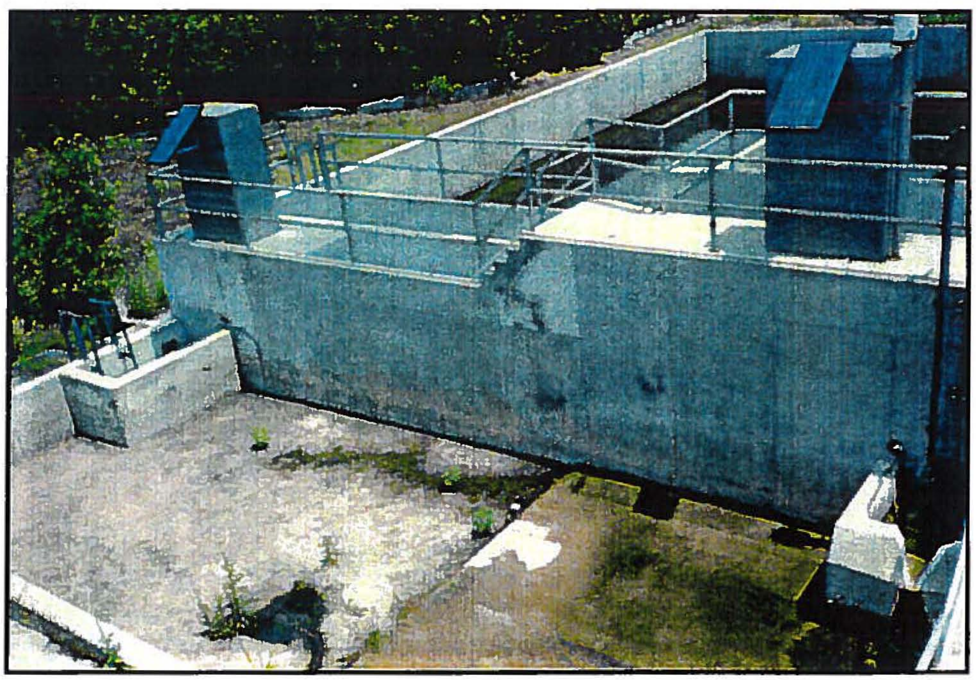


Figure 20. Stormwater monitoring station at Barton Ridge Plaza, viewed from filtration side.

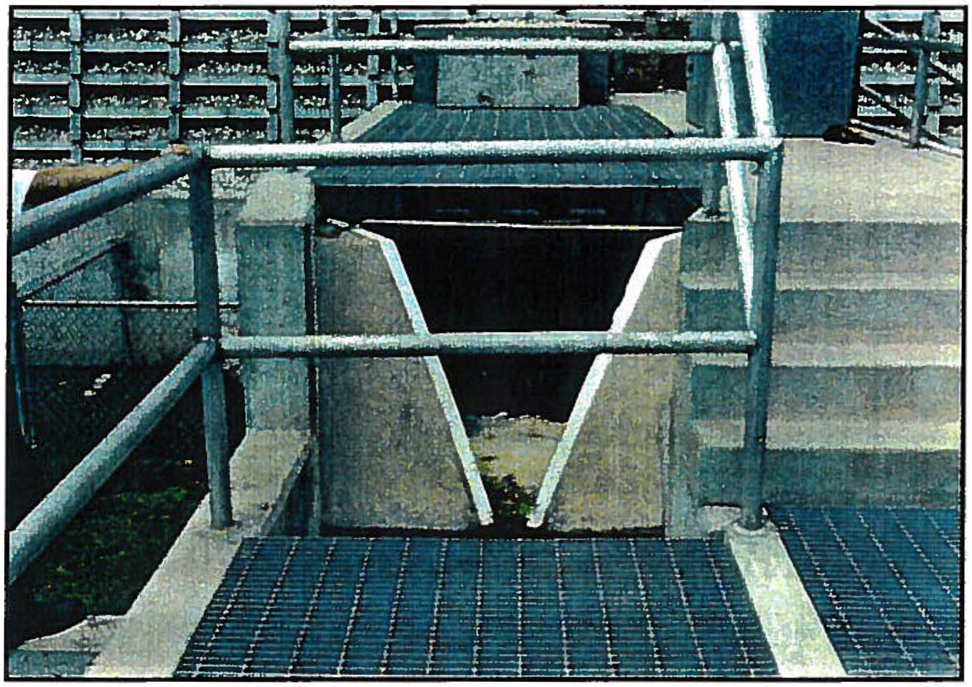


Figure 21. An H-flume at the monitoring station of the inflow at the Barton Ridge ponds.

Figure 22. An H-flume at the monitoring station of the outflow from the sedimentation pond.

Figure 22-24 show flow measurement structures at three other monitoring stations. The grant study team installed a sampler and a flow meter at each of the 3 stations. At the outflow, there is a 120-degree V-notch weir that provides good flow data. The flow measurements at the outflow of sedimentation pond and at the overflow are not as accurate as those of inflow and outflow stations. There is a 1-foot H-flume at the monitoring of outflow from the sedimentation pond. The flow is somewhat turbulent during high flows because of a short approach channel. During low flows, the depths of flows were too low to provide accurate measurements. The overflow measurement structure is a 7-foot side weir that presents some problems in developing an adequate flow rating equation. This study has not conducted detailed analysis on flows of these two stations. The pond is not treating overflows. Nevertheless, the impact of overflow was described in Section 4, "Characterization of Barton Ridge Plaza Ponds." The impact of flow measurement on water quality (for mid-outflow) was not significant. The team has tried to quantify the impact by varying the flow rating equation (flow rate versus depth of flow relationship). The EMC values were little impacted due to this variation.

Monitoring Stations for St. Elmo Wet Pond: Three storm water monitoring stations were established at the SEP wet pond. Figures 25-30 show the outlooks and details of the 3 stations. At the east-side inflow station, there are 2 flow meters, 2 samplers, and a 2-foot (width of the throat section) trapezoidal flume. The flow meters measure water depths at 2 locations in order to provide adequate measurements under both free and submerged flow conditions. The flow meters trip two samplers to operate at two different flow pacings in order to collect samples that can cover the entire time base of the runoff hydrograph. The west-side inflows are often under submerged conditions because of the back water from the wet pond. The grant study team installed one flow meter and one area-velocity meter in order to measure the depths and velocities of flows in a 54-inch concrete pipe. The team can estimate the flows properly using slope-area method (Herschy, 1985) by knowing the water depths inside the pipe and at the pond. The area-velocity meter can measure both velocity and flow depth and can probably be used as a

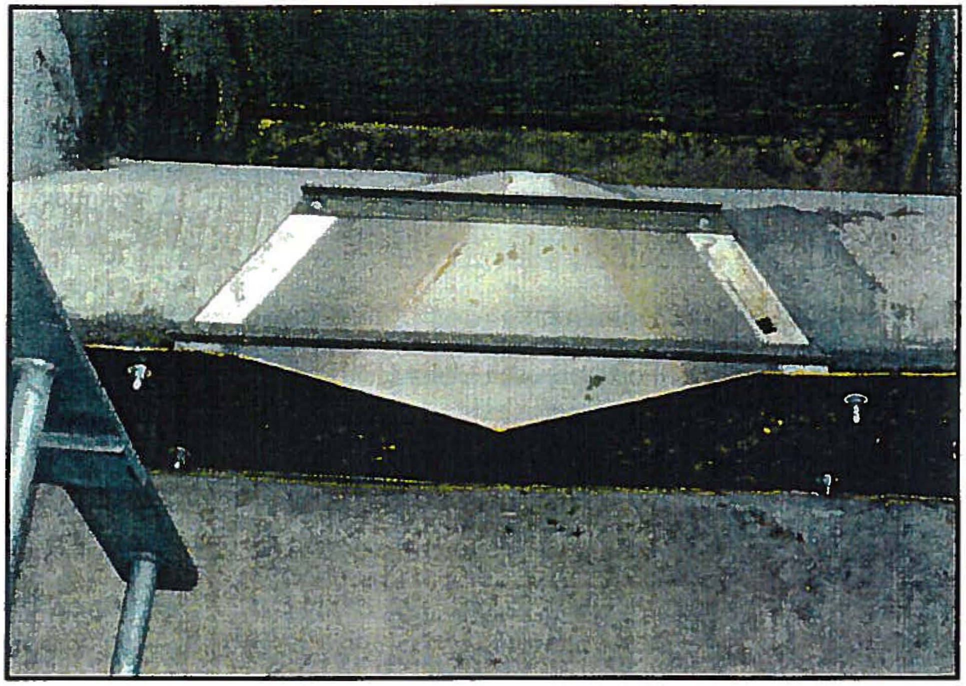


Figure 23. A 120 degree v-notch weir at the outflow monitoring station.

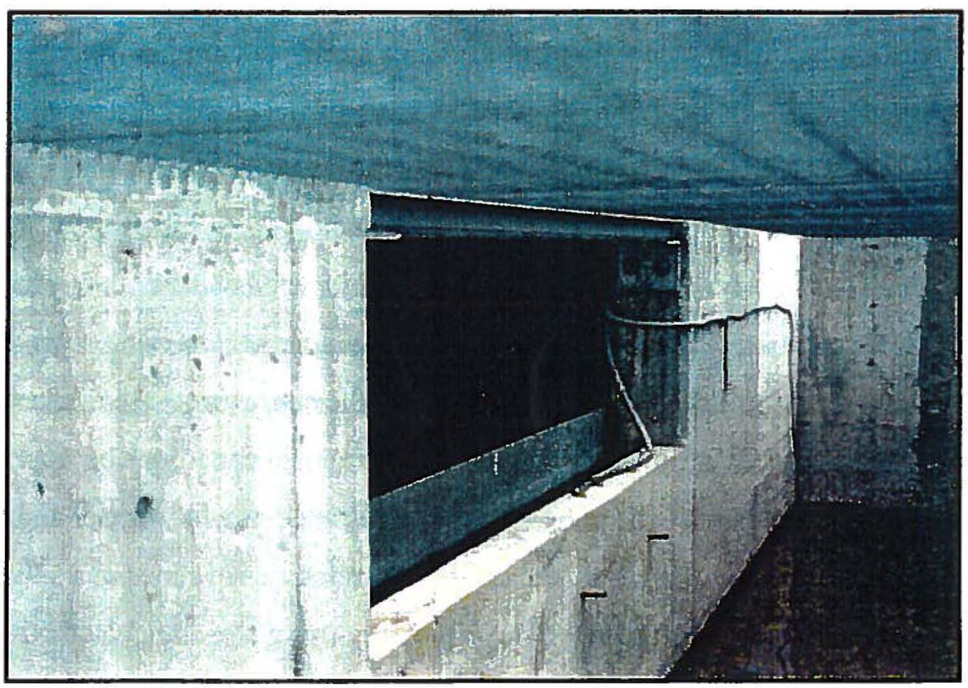


Figure 24. A rectangular weir at the overflow monitoring station - the spillway in the splitter box.

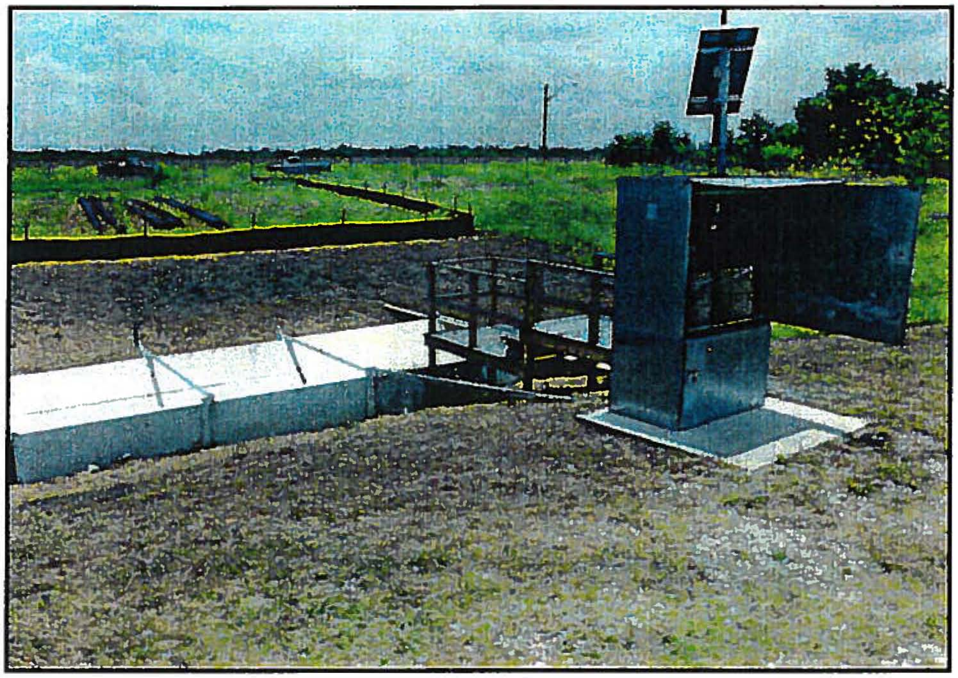


Figure 25. Stormwater monitoring station at the east-side channel of the inflow to the St. Elmo Wet Pond.

Figure 26. A trapezoidal flume and its approaching channel at the east-side inflow monitoring station.

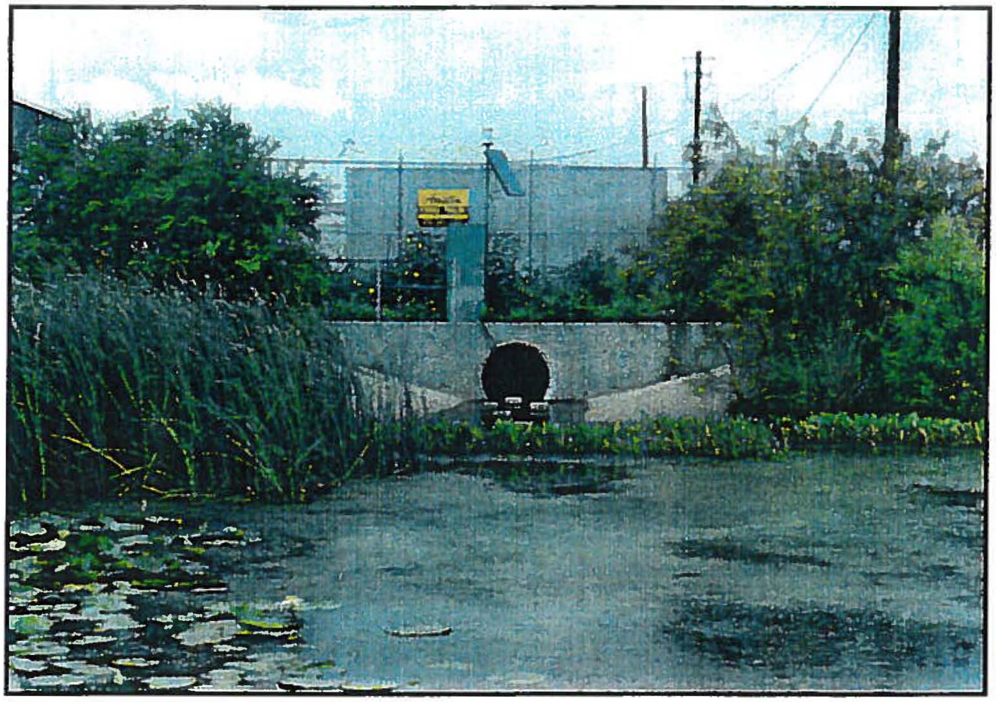


Figure 27. Stormwater monitoring station at the west-side pipe of the inflow to the St. Elmo Wet Pond.

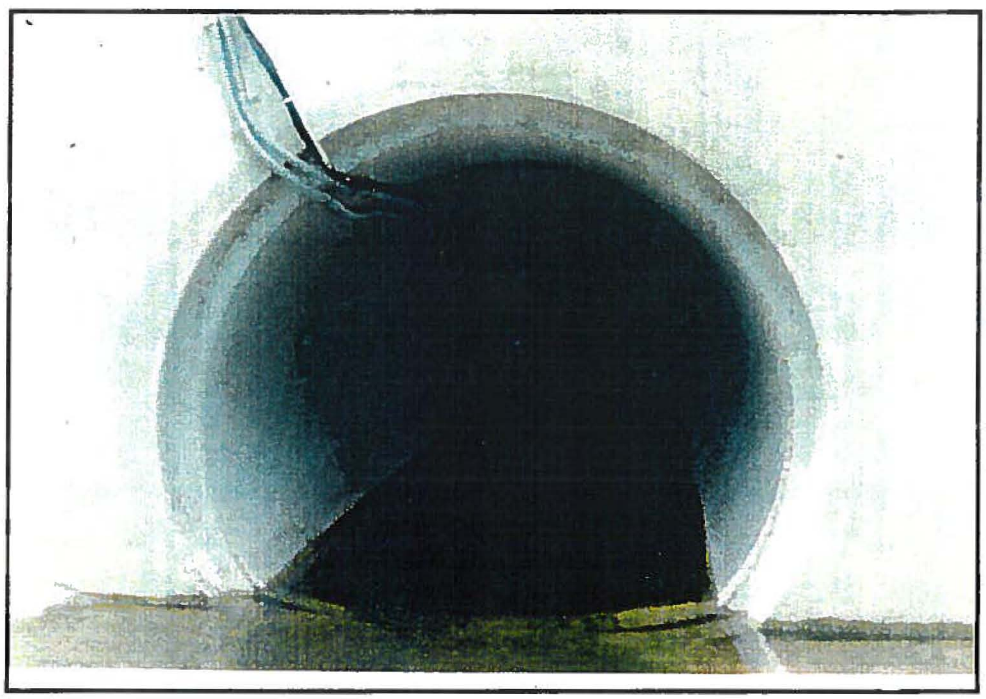


Figure 28. Flow measure through depth and velocity readings at the west-side inflow monitoring station.

Figure 29. Stormwater monitoring station at the outlet of the St. Elmo Wet Pond.

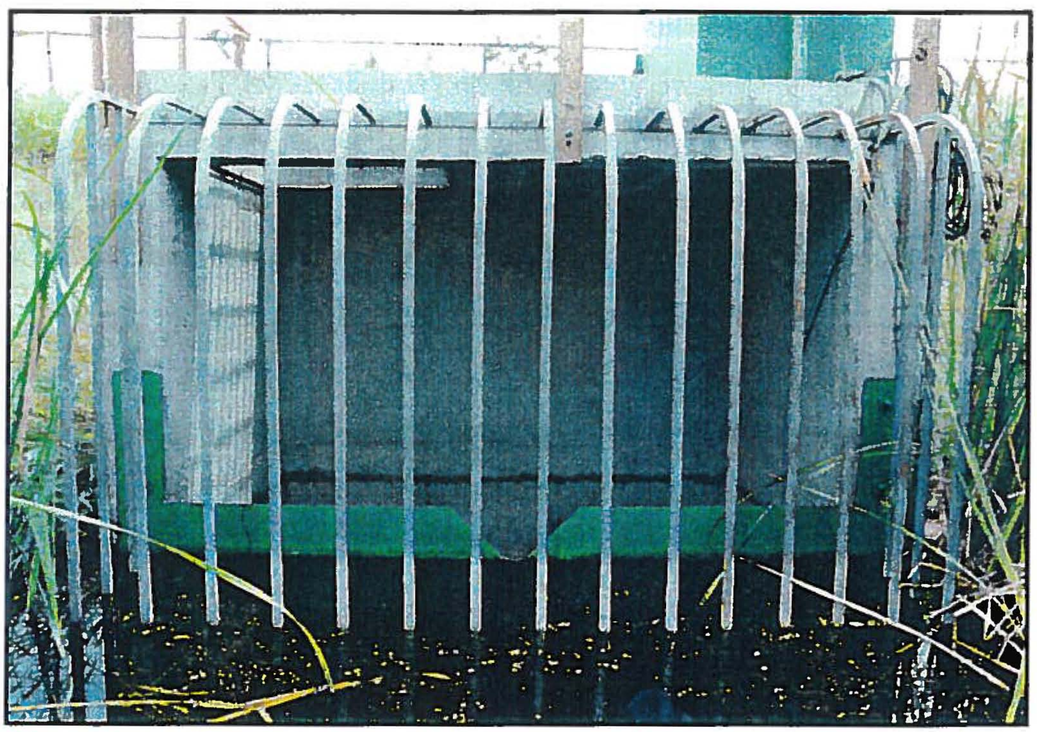


Figure 30. A compound weir flow measurement structure at the outflow monitoring station.

check of the flow values estimated by the slope-area method. This meter, however, could not work properly due to the impact of backwater from the wet pond.

For the outflows, there is a compound weir that has a 90-degree V-notch in the middle and an 8-foot rectangular weir on top of the V-notch. The pond water seldom exceeds the 9-inch maximum head of the V-notch weir. The flow measurement by the weir is mostly accurate except for minor errors caused by the contraction of flow at the edges of the weir.

3.8 Wet Pond Functional Analyses

Removal of stormwater pollutants in a wet-detention system is accomplished by a number of physical, chemical, and biological processes. Gravity settling removes particles. Flocculation occurs when heavier sediment particles overtake and coalesce with smaller, lighter particles to form still larger particles. Biological removal of dissolved stormwater pollutants includes uptake by aquatic plants and metabolism by phytoplankton and micro-organisms that inhabit the bottom sediments. Pollutant removal primarily occurs during the relatively long quiescent periods between storms. Accordingly, the permanent water pool is especially vital, since it permits treatment to occur between storms, reduces runoff energy, and provides a habitat for aquatic plants and algae (the biological filters that remove dissolved nutrients and metals). The subject 319 grant primarily focused on monitoring the outflows and inflows to the wet pond, a direct measure of the removal efficiency; however, monitoring within the pond provides insight on the processes which may make one pond perform differently from another. This section examines the monitoring of sediments and water quality parameters within the pond.

One product of monitoring a control structure is identification of pollutant levels in the runoff draining to the pond. The presence or absence of certain pollutants can often help identify the sources. Some of the toxic constituents may be at levels which are below detection limits in the influent or the water column. However, due to the concentration of these pollutants through adsorption processes with inorganic and organic sediment particles, they may be easily identified in the settled sediments. Because of its role in identification of low level toxic pollutants, sediment in the St. Elmo wet pond was evaluated by constructing a set of sediment monitoring traps to collect the settled materials in the pond.

Within the water column in the pond, some indicators of the processes occurring and the functioning of a pond over time are the pH, redox potential, temperature, and hardness (often measured as TDS or conductivity). As discussed in Section 3.8.3, these indicators were measured with a Hydrolab H2O probe to examine the temporal changes within the pond during and between storm events.

3.8.1 Pond Sediment Sampling

Sediment characteristics were monitored at three locations in the pond, as described in the workplan. This effort, however, was not grant funded due to the lack of remaining funds before collection of sediment samples, and because this was an additional task proposed with the revised work plan. The initial plan was to sample the pond representatively on a spatial basis, therefore, sediment traps were deployed at sites near both influents and the effluent.

At each site, sediment traps were placed at the bottom of the pond. Locations were named with the same convention as the influent and the effluent monitoring stations were named. "SWI" is the designation for the location close to the East influent, "SWJ" is used for the location close to the West influent, and "SWE" is used for the location close to the effluent of the pond. Locations for the sediment traps are depicted in Figure 31.

Two and a half gallon glass mason jars were used to collect sediment. The jars were placed into a stable base which was fabricated for this application. A PVC pipe 10 inches high and 10 inches in diameter was placed vertically into a concrete base with the dimensions of (24"x24"x4") to ensure that the sediment collecting jars were stable during the accumulation period. The total height of the sediment trap and its components was 15 inches. Over a one year period, thirty of these jars were placed at the three locations; two

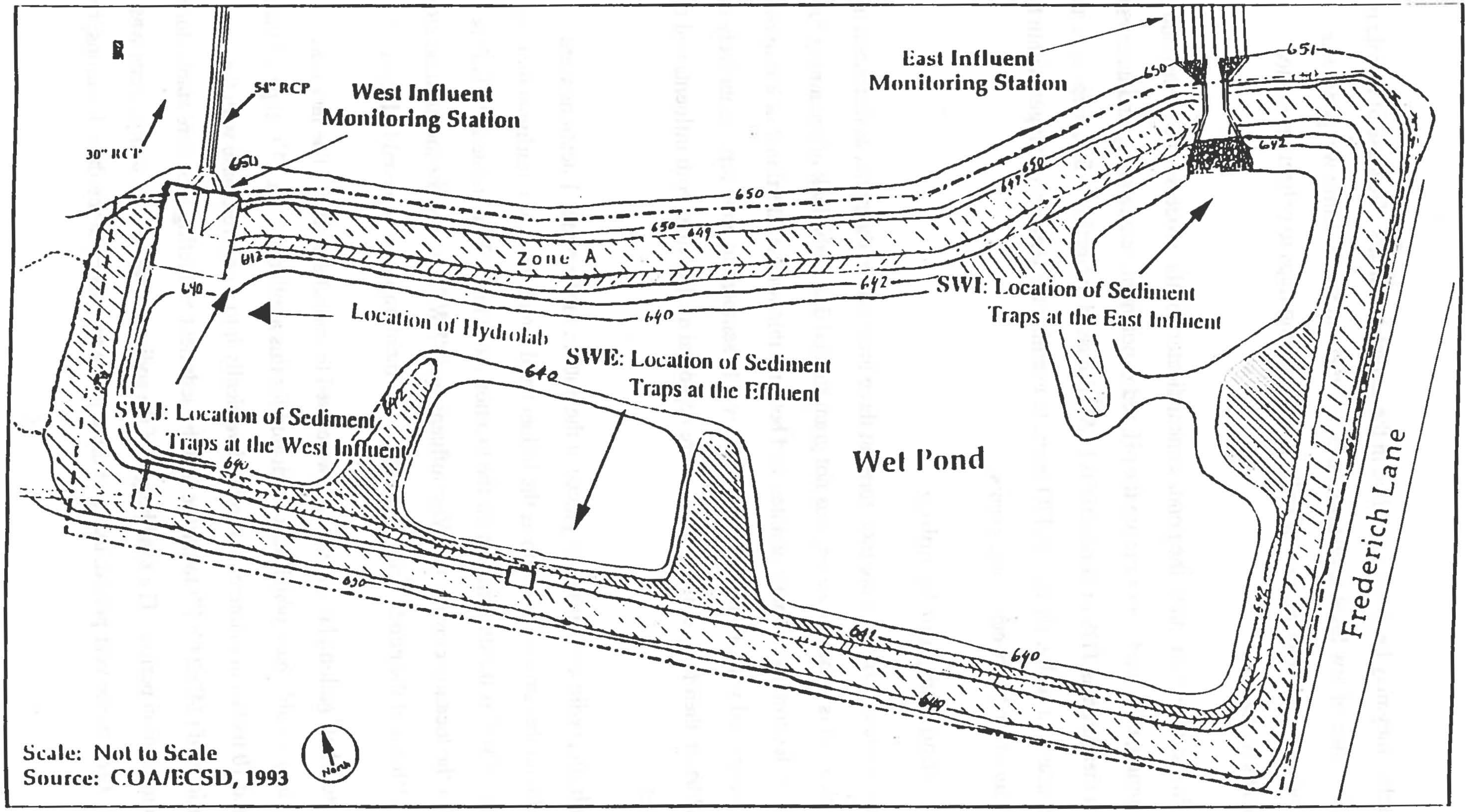


Figure 31. Locations of Sediment Traps and Hydrolab Probe in St. Elmo Wet Pond

duplicates at each site at approximately quarterly intervals. Every jar had an identification label which showed location, placement time, site abbreviation and letters "A" or "B" to indicate duplicates.

In January, April, July, October, and December 1995, the grant team and project manager visited the site for placement of the sediment traps. First, the sediment traps were properly labeled, the sites were leveled, and the sediment traps and their components were placed in corresponding locations at equivalent depths. The monitoring team inspected the pond on a regular basis to ensure that the traps were intact.

All of the sediments traps were collected on April 22, 1996, with only one person retrieving the jars to avoid resuspension of the sediment from the bottom of the pond. Before each jar was taken out of its place in the pond a threaded lid was screwed to the jar's neck, securing the contents against disturbance. All the samples were transported with a canoe and placed onto the dock. On approximately fifty percent of the jars which were removed, the labels had come off or were not legible. To address this problem, jars (and ice chests) were grouped based on the locations. The jars were then re-labeled and placed in ice chests. The same process was repeated for all three sites. After completion of the sample collection, the jars were delivered to the Lower Colorado River Authority Laboratory.

Test results revealed great variation in duplicate samples and inconsistent amounts of sediment within each jar. Several different factors may have caused the unexpected test results. The lack of labels on the bottles greatly increased the uncertainty of the data, and affected reliability of the test results. Therefore, the data will not be used to describe spatial variations within the pond or sedimentation rates.

The second possible source for variation is the high algae growth in the pond; the day the samples were collected, very high levels of algae were observed in the pond, as well as an accumulation of algae in the jars. While the temporal and spatial distribution of algae may result in highly variable results over time and between duplicates, the bio-accumulation and settling of these plants is part of the functioning of the pond.

The primary focus of the data analysis will be on the use of sediment analyses to detect toxic constituents which are below detection limits in the influent, effluent and water column. The source and treatment of these constituents might go undetected without sediment sampling, yet accumulate in receiving water sediments.

3.8.2 Sediment Results

From each jar, separate analyses were conducted for the sediment and the supernatant collected in the jars including metals, TPH, TOC and the dry weight. PAH analyses were done in the COA Environmental Resource Management laboratory for sediment samples only to detect the presence of these constituents. The results are compared with water column levels and with EPA toxicity levels to give an indication of accumulations which could occur in receiving water bodies if no controls were implemented.

Figures 32, 33, and 34 display results from sediment and supernatant analyses of lead, copper and zinc. These charts show that few of the supernatant samples (representative of pond water) showed metal levels above the detection limits. Several samples did have detectable zinc concentrations and one had detectable copper concentrations, however, all of the levels detected were below the fresh water chronic toxicity criterion as established in the Texas Administrative Code (30 TAC 307). The National Standards and Trends Program (NOAA, 1991) established toxicity levels for sediment samples; Effects-Range Low (ER-L) is a concentration on the low end of the range of concentrations having a biological effect and Effects-Range Medium (ER-M) is a concentration near the mid point of the range of concentrations with known biological effects. An examination of the sediment levels shows, unlike the supernatant, that metals were detected in all samples, and some metals, particularly zinc, had levels above ER-L and ER-M. The sediment results are described in more detail below.

<u>Copper</u>. Copper is very toxic and relatively accessible to biological life. Freshwater organisms can be acutely sensitive at concentrations as low as 16.7 ppm in water. The sediment concentrations in this pond do not exceed the ER-L levels of 70 mg/kg listed by

Figure 32. Lead Values in Sediment and Surface Water at the Effluent (SWE) and at the Influents (SWI, SWJ) of St Elmo Wet Pond

TAC fresh water chronic toxicity criterion for Pb=0.007 mg/l
detection limit for Pb in water=0.05 mg/l

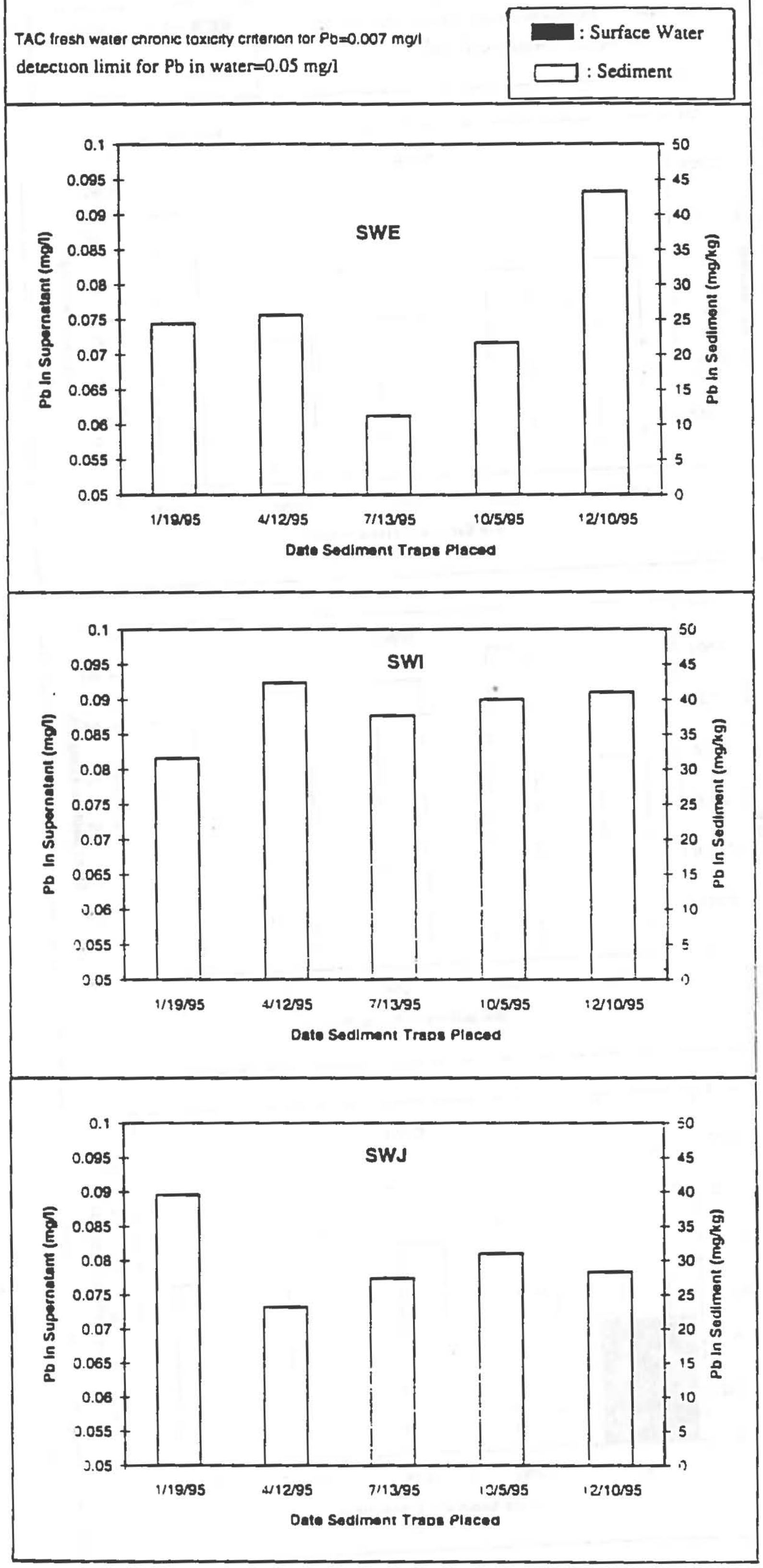


Figure 33. Copper Values in Sediment and Surface Water at the Effluent (SWE) and at the Influents (SWI. SWJ) of St Elmo Wet Pond.

TAC fresh water chronic toxicity criterion for Cu=0.022 mg/l
detection limit for Cu in water=0.01 mg/l

: Surface Water
: Sediment

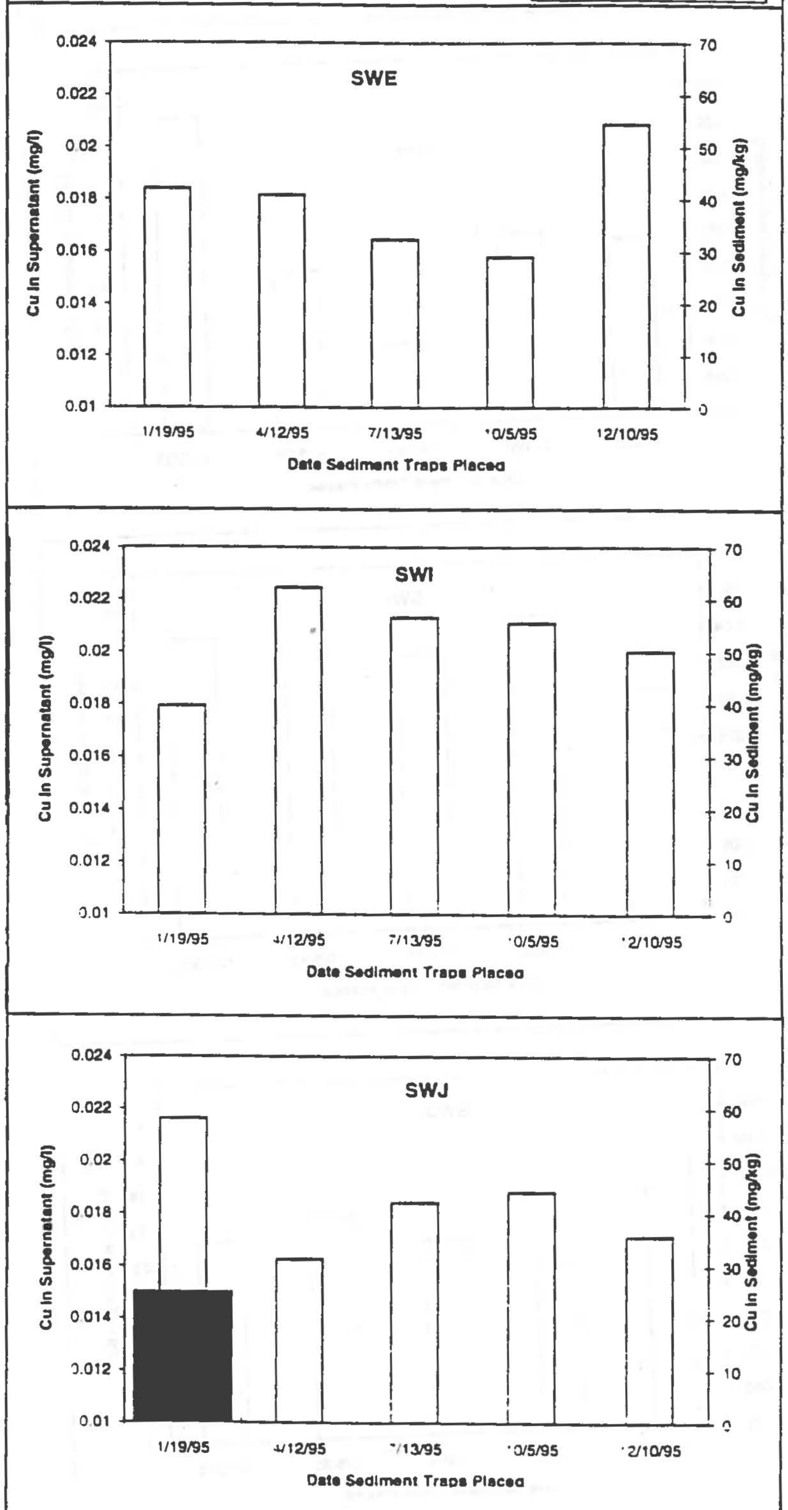
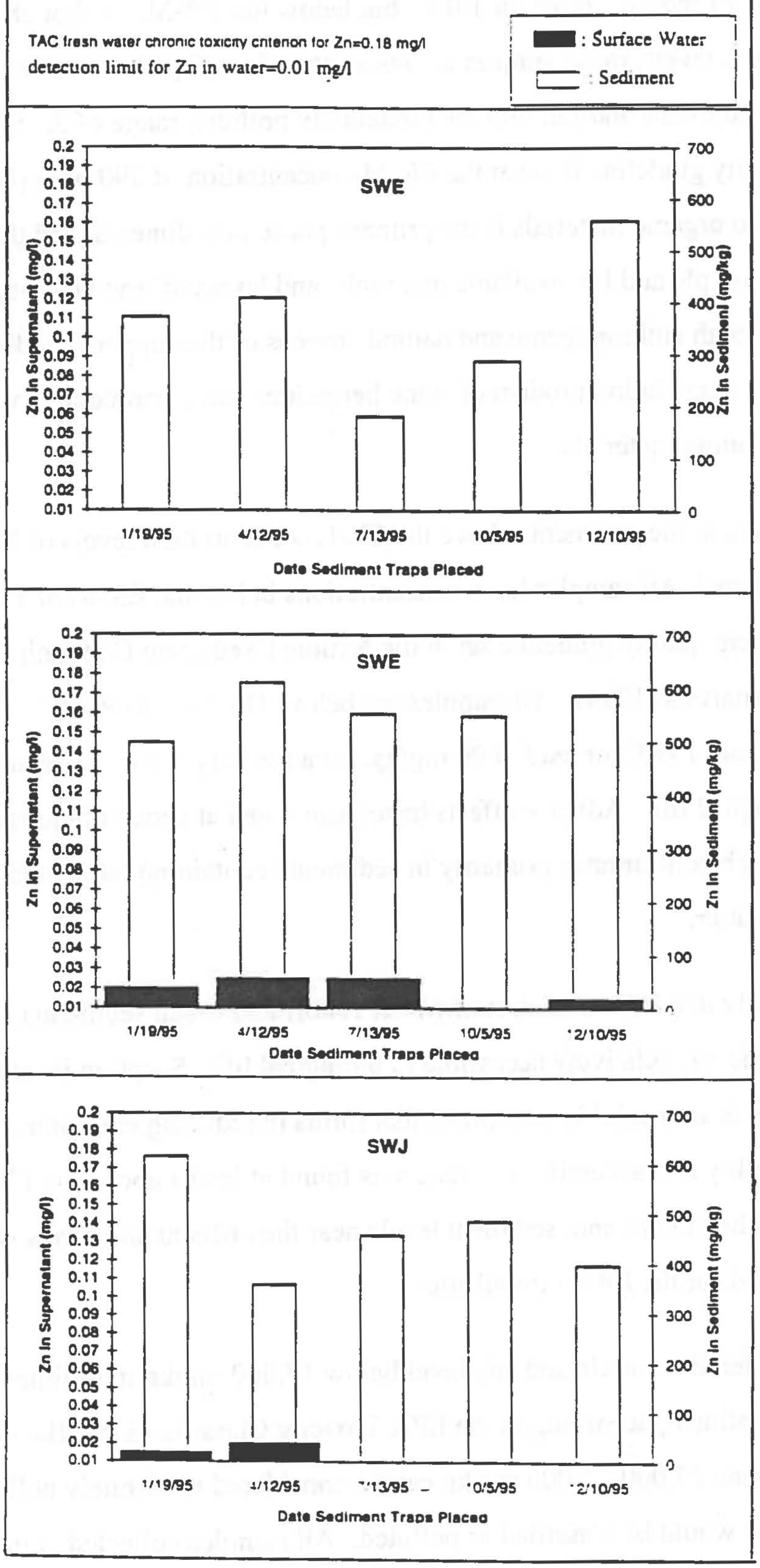


Figure 34. Zinc Values in Sediment and Surface Water at the Effluent (SWE) and at the Influents (SWI, SWJ) of St Elmo Wet Pond



NOAA in any of the samples analyzed, except for one date. On 1/19/95 the results show a concentration of 73 mg/kg, above the ER-L, but below the ER-M. Although the results do not exceed ER-L levels, most samples are above the 25 mg/kg toxicity classification for non polluted sediments and fall into the moderately polluted range of 25-50 mg/kg. The sediment quality guideline is set at the ER-M concentration of 390 ppm (USEPA, 1994). Sorption to organic materials is the primary phase in sediments, and that sorption is very dependent on pH and Eh, available materials, and levels of iron and magnesium oxides. There are both anthropogenic and natural sources of the copper found in stormwater. It is a degradation product of some herbicides and a component of automobile brake lining materials.

Lead. Lead appears in the sediments above the ER-L concentration levels of 35 mg/kg in most samples analyzed. All samples have concentrations below the ER-M of 110 mg/kg, which is the sediment quality guideline set in the National Sediment Contaminant Source Inventory: Point Analysis (1994). All samples are below The EPA Toxicity Classification (Baudo, 1990) for lead of 90 mg/kg. Lead is very toxic and relatively accessible to biological life. Adverse effects have been noted at concentrations as low as 1.0 ppm in water. Pb concentrates primarily in sediments containing large amounts of clay and organic matter.

Zinc. Zinc is usually detected in most stormwater runoff and urban sediments. Zinc is also considered toxic and relatively accessible to biological life. Sorption increases with pH and zinc sulfide is an insoluble precipitate that forms in reducing environments and will limit zinc mobility and accessibility. Zinc was found at levels above the ER-M of 270 mg/kg at all influent sites and, sediment levels near the effluent site levels were above either the ER-L or the ER-M for all sites.

Iron. Iron is considered nontoxic and any level below 17,000 mg/kg in sediment is thought to be non-polluted, according to the EPA Toxicity Classifications (Baudo, 1990). Levels of iron between 17,000-25,000 mg/kg can be considered moderately polluted and above 25,000 mg/kg would be classified as polluted. All samples collected at the influent sites have concentrations below 17,000 mg/kg, and therefore fall into the nonpolluted range using this classification system. However, six of the samples from the effluent site showed concentrations above 17,000 mg/kg. Iron oxides and magnesium oxides will increase the precipitation of other metals to the sediments. The large amount of iron in this pond could contribute to an increased level of metal concentrations in the sediments.

The range of sediment values for these constituents were compared with grab samples from other water quality control structures that have been sampled in the Austin area. The differences in constituent levels are related to the land use in the drainage area for the site. The following sites were included, and the results are shown in Table 5.

Examining Table 5, the levels in St. Elmo Pond are similar to those found at the Convention Center OSTC, except for the zinc and copper levels which were higher than all but the service station facility (Waller OS). One important factor to note is that, despite some elevated levels of toxics in the sediments, City testing of sediments at the Jollyville SF Pond and the Waller OS indicate that the toxics are strongly sorbed and all have passed the TCLP tests.

Careful sampling of sediments, with accurate measures of accumulation rates would provide documentation of the removal and quantification of the prevention of toxics from reaching the receiving waters by the control structures. This information is extremely important in determining the cost-effectiveness of various structures for NPS pollution controls.

3.8.3 Time-Scale Effects

Time-scale effects were demonstrated with the "Hydrolab," a water quality multi-probe instrument. The Hydrolab H2O multi-probe is an on-line transmitter of in-situ temperature, pH, dissolved oxygen (both mg/l, and percent saturation), conductivity (milisiemens/cm, microsiemens/cm, or resistivity K ohms-cm), and salinity (parts per thousand or total dissolved solids in mg/l), depth (either level or total depth), turbidity

Table 5. Toxics in Sediments from WQC Structures

	St. Elmo Wet Pond			9/28/93 Cook Wet Pond	5/24/94 Woodhollow Wet Pond	5/24/94 Convention Center Wet Pond	9/30/93 Convention Center OSTC	9/28/93 Waller OS	5/30/96 Austin Rec. Ctr OSTC	9/28/93 Jollyville Sand Filter
	MAX	MIN	MEAN							
Pb mg/kg	49.7*	8.49	21.5	31	220#	18	48*	1075#	46*	113#
Zn mg/kg	750#	319#	471#	55.4	128*	44.8	105	1709#	276#	381#
Cu mg/kg	73.3*	29	46.6	6.8	13.3	7.1	9.5	306#	12	17
TPH mg/kg	14,643	987	5,202	86	208	51	1,860	87,850	350	772
TOC mg/kg	36,298	445	4,414	26,200	42,300	4,080	12,700	247,000	65,300	43,800
PAH ug/kg	10,210			<DL	<DL	<DL	14,060	<DL	11,000	87000
Grain Size										
>2.00mm	<.1%	<.1%	<.1%	<.1%	34%	<.1%	<.1%		<.1%	<.1%
.075-2.00 mm	88%	36%	57%	22%	56%	45%	73%		54%	41%
.005-.075 mm	64%	13%	35%	46%	4%	44%	21%		43%	50%
<.005 mm	<.1%	<.1%	<.1%	33%	6%	11%	6%		10%	9%

* Above ER-L
\# Above ER-M

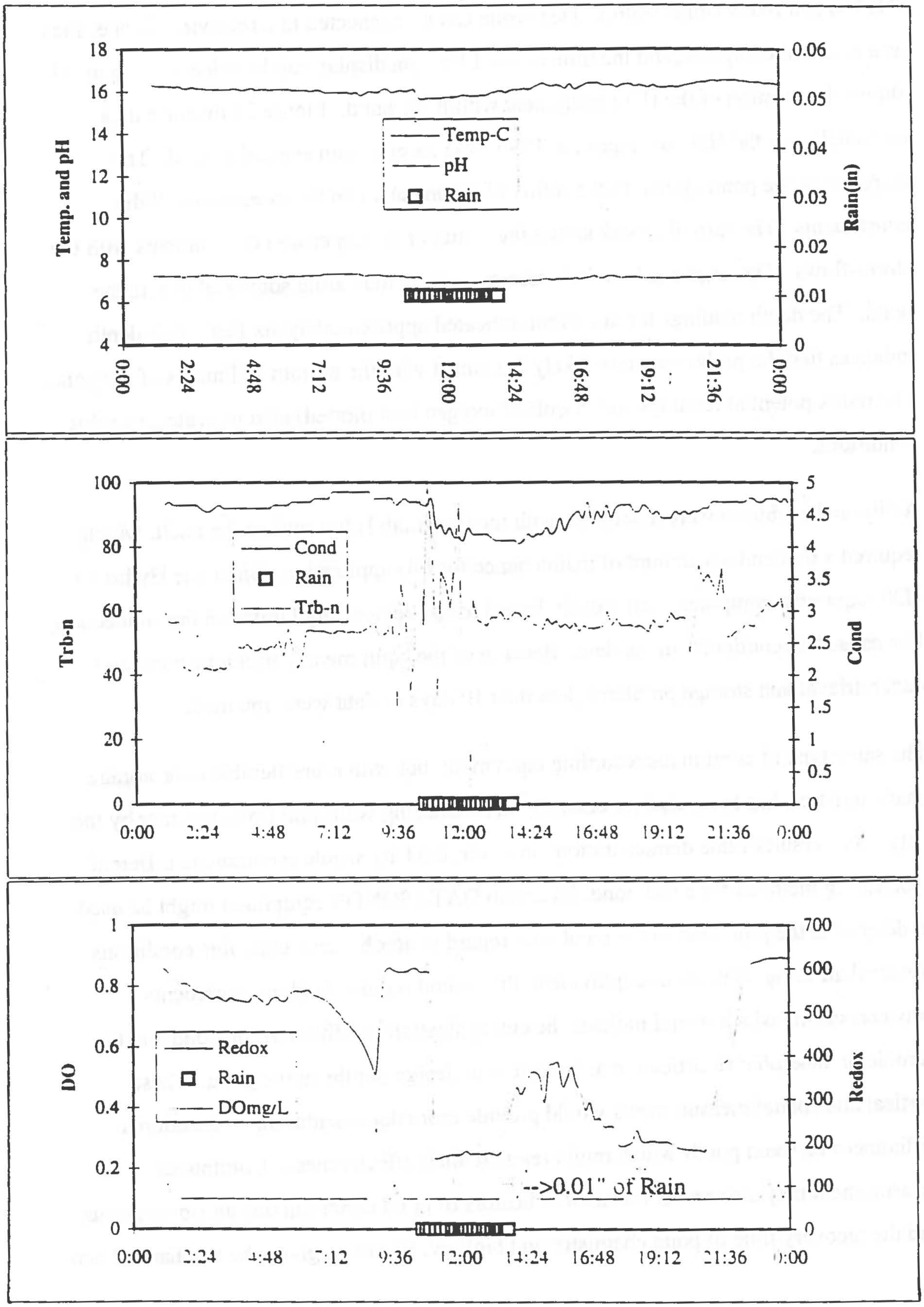
OSTC- Oil/Sedimentation Treatment Chamber
OS - Oil Separator

(NTUs) and redox (milli Volts). This probe can be connected to a receiving device, such as a personal computer, and the time interval for data display can be selected. Figure 31 shows the location of the H2O equipment within the pond. Figure 35 displays data collected from the H2O on April 22, 1996, when a brief rain event occurred. The response of the pond system to the influx of stormwater can be observed in all the constituents. The turbidity peak shows the influx or re-suspension of sediments with the storm-flows. The response functions recover rapidly indicating some stability in the pond. The depth readings for this event indicated approximately six feet. This depth indicates that the probe was most likely in contact with the bottom sediments of the pond. The redox potential readings and dissolved oxygen (not plotted) also indicate anaerobic conditions.

Additional problems were associated with the Hydrolab H20 multi-probe itself, which required a tremendous amount of maintenance for this application. Since the Hydrolab H20 required a computer continuously linked to the device, any failure on the connection line caused discontinuity in the data. Because of the equipment, communication, and data retrieval and storage problems, less than 10 days of data were obtained.

The same type of continuous recording equipment, but with more flexible data storage characteristics, has been used successfully in monitoring wells and flowing water by the City. As a result of this demonstration, however, the City would recommend different monitoring methods for a wet pond. Hydrolab DATASONDE equipment might be used to determine the processes in the pond with regard to aerobic and anaerobic conditions. Rather than using continuous deployment, this would require field measurements between storms which would indicate the eutrophication condition of the pond and the aerobic or anaerobic stratification at the different design depths in the pond. These vertical and spatial measurements would provide more documentation on functional differences between ponds which might regulate their effectiveness. Continuous measurement may also reveal transient indicators of pond condition during storm events and the recovery time of pond chemistry and biology; however, given the mechanical and

Figure 35. H2O Measurements on April 22nd 1996 in St. Elmo Wet Pond



equipment problems noted in this project, much more planning and testing should be done before deployment. Grant funds were used in purchasing the equipment for this demonstration, but were not used for personnel or analysis time and efforts.

However, the primary concerns associated with a water quality control structure are still effectiveness (measured through concentrations in influents and effluents) and design features which affect processes and therefore, effectiveness. Further recommendations for monitoring methodologies that would supplement the standard effectiveness measures would include careful deployment of additional sediment traps and quantification of sediment accumulations spatially and through time, including concentrations of toxic constituents which may be below detection limits in influents and effluents.

3.9 Quality Assurance for Stormwater Monitoring Process

The COA Storm Water Monitoring Program (SWMPM) has a working process that consists of a series of task elements. These elements include watershed data documentation, flow measurement, sample collection, sample transport, lab analysis, and data processing. For each task element, the program team prepared a job flow chart. Within each flow chart, there are quality assurance/quality control (QA/QC) checks or plans to ensure the quality of products generated by this task.

<u>Watershed data documentation:</u> As described before, this study used GIS software to develop watershed data such as basin boundary, sewer network, and ground cover information. This practice has minimized the error created by manual estimates. In addition, the project staff further verified the information through field inspections during and before runoff events. The errors associated with this task are minimized.

<u>Flow Measurement:</u> Except for random error, there are two types of flow measurement errors. One type is systematic error which is generally induced by equipment and structure irregularities The other type is spurious error produced by human error or equipment malfunction. For this grant study, the COA mostly used manufacturer provided structures that comply with the manufacturer's lab-testing conditions. The bubbler type flow meters are generally accurate for standing water and for a flow velocity of 5 feet per second (fps) or less. The project staff confirmed this finding through observing tests conducted in the field and in a hydraulics laboratory. The flows at all monitoring stations satisfy the conditions of the 5 fps limit.

Nevertheless, the study cannot avoid some specific errors. For example, the arrangement of flow measurement structures and equipment cannot meet exactly the lab-testing conditions. The flow measurement of flumes for submerged condition is less accurate than that for free flow conditions. There are also errors associated with the slope-area method (Herschy, 1985) in establishing the flow rating equation for the west-side inflow station at SEP. On the average, the total errors associated with the flow measurements for each monitoring station (except for the overflow and mid-outflow stations of BRP) are within 10 to 15 percent as evidenced by the characteristics of the flow measurement structures and the slope-area method. The impact of this error on EMC values are within 2 percent as demonstrated by the computations of EMCs for the BRP mid-outflow using two different sets of flow data. Appendix H0 (H0-2 and H0-3) provides the details of the flow rating studies.

Sample Collection: The monitoring staff routinely collect samples utilizing a remote-controlled operation. The collection follows a detailed procedure as specified in the SWMPM operation manual (1993a). The staff also collect field duplicate, equipment blank, and trip blank samples (COA, 1994) for quality assurance in data collection. Appendix H1 provides data analyzed from these samples. Except zinc and nitrate (NO_3), these data show little contamination in the processes of sample collection. The zinc concentration value for an "equipment blank" sample is high while the values of other parameters for the sample are under detection limits. There are also high values of zinc for a few "equipment blank" samples collected at other COA monitoring sites. Some lab analysis errors associated with the testing of zinc during this period. Nevertheless, the event concentration data for zinc are generally consistent with those of other ponds previously monitored by the City of Austin (COA, 1990a). For nitrate, there was a bottle washing problem in the laboratory during the same period in 1995. The lab uses a nitric acid rinse in the bottle washing process as required for bottles collecting metal samples. Obviously some bottles were not thoroughly rinsed and may have been contaminated with trace amounts of nitric acid. This contamination is evidenced by extremely high concentration values, high ratios of NO_3 to TKN concentrations (3 to 1), and high concentration values of equipment and trip blank samples. As a result of this contamination, a small portion of the nitrate concentration data was deleted from the database. A criterion was established to delete nitrate data if, nitrate concentrations are greater than 5.0 mg/l, or if they are greater than 2.0 mg/l and the ratio of NO_3 to TKN are greater than 4. On-going meetings with laboratory staff were initiated to address these QA/QC concerns and alternative bottle washing practice put in place to prevent further occurrence. Due to the contamination, the nitrate data in this report is not as accurate as those of other pollutant parameters.

For BMP sampling, it is fairly difficult to collect a set of samples that provide adequate data to compute paired inflow-outflow EMCs. The monitoring staff has set a standard for sample collection at a BMP site. The sampling of a runoff event should cover the first flush and at least "60 percent" of the runoff volume. The EMC data used in this study satisfies or exceeds this "percentage" standard. The grant study team has studied the concentration data of many monitoring sites (COA, 1993a). Equations were established to relate the concentration values to the percent volume of cumulative runoff during a runoff event. Impacts of sampling "percentage" on the EMC values were estimated. It was found that the "60 percent standard" can give an average error of about 4 to 10 percent depending on the type of pollutant parameters. On the average, however, the errors of EMC estimates for various pollutant parameters for this study should be within 4 percent. Appendix H2 is a table showing the relationship between percent error of EMC estimate and percent volume of total runoff being sampled.

Sample Preservation and Transport: The monitoring staff of the grant study team preserve, organize and deliver samples to the laboratory in accordance with specified guidelines (COA, 1986 and 1993a). The staff used "chain of custody" forms (Appendix H3) to organize sample preservation and delivery. The staff also use field notes

(Appendix H3) to record any irregularities. There were, however, some problems concerning sample holding time.

For BMP outflow sampling, the sample collection usually lasts more than 24 hours. Due to man-power limitations, the staff often delays sample delivery. For the bacterial parameters such as fecal coliform and fecal streptococci, the sample holding time frequently exceeded the specified limits. The errors associated with the concentration measurements of these parameters, however, may not be significant. A comparison of the bacteria data between this and previous COA studies (COA, 1990a and 1990b) indicates that the inflow and outflow bacteria concentration values are generally reasonable. Other than bacteria, this study used no data obtained from analyzing samples that exceeds holding time. This study has not charged the grantor any expenses associated with the analyses of samples either exceeding holding time or being contaminated.

Laboratory Analysis: The Walnut Creek Laboratory of the COA's Water and Wastewater Department conducts laboratory analysis for the COA SWMP. The laboratory provides quality control (QC) charts for storm water sample analysis. Based on the QC data on spike recovery and duplicate analyses, the grant study team estimated percent errors associated with the concentration measurements. The maximum average error of measurements for the three year period (1993-1995) is about 12 percent, ranging from 6 to 27 percent, depending on the pollutant parameters. The estimated errors associated with different parameters are included in Appendix H. Appendix H4 provides lab's representative QA/QC data for three years (1993-95).

Lab analysis results sometimes report concentration values below detection limits. Some concentration measurements for metals such as Cd, Cu, Pb, and Zn were found below detection limits. In these cases, the lab presents concentration data with a "less than" sign in front of a specific value. For simplicity, this study has assumed that the concentration value for an undetected data is the average of zero and the lab specified, "less than" value. This assumption will have minor effects on the inflow and outflow metal concentrations, and therefore slightly impact the values of treatment efficiencies for both ponds.

Data Processing: Data processing for this study is a long, tedious process. It starts from data downloading to the data merging of flow and concentration files. Each merged file for a station has records of several hundreds to several thousands. The processing used a system of computer programs to develop and organize data files. It also passes through many data reviews and screenings to ensure data quality. The staff of the grant study team first screen and separate the 1-minute-increment rainfall and flow level data into individual level-hydrographs. This step involves a great number of quality checks. The staff further convert the level hydrographs into flow hydrographs using a flow rating table or equation. There is an additional quality check about the adequacy of the equation. The processing reviews and organizes concentration data files using field notes, hydrograph data, and "chain of custody" forms. This step ensures the correctness of timing and values of concentration data. The errors on data processing are mostly associated with the methods of calculation and the data review processes. This study has minimized these errors by following and repeating the specific steps in a flow chart . Data errors associated with the methods of calculation (for example, method for integration of flow volumes) and the review processes should be fairly minor.

Appendix H5 presents a flow chart to show the tasks and quality control checks for the processing of storm water data.

4 EVALUATION AND CHARACTERIZATION OF STRUCTURAL BMPs

The COA started monitoring structural BMPs in the early 80's. The City has evaluated several water quality control ponds, grass swales or channels, and small structural BMPs. This grant study tested wet pond and sedimentation/filtration basins with significant design improvements. The following sections evaluate the performance of these ponds and characterize their effectiveness for NPS pollution control. The study also discusses key criteria for designing and maintaining wet pond and sedimentation/ filtration basins for most effective functioning.

4.1 Methods for Evaluation of Pond Treatment Efficiencies

This study presents two methods to evaluate the treatment efficiency (and/or removal efficiency) of a water quality control pond. Method A uses the mean of treatment efficiencies for individual runoff events to represent the mean treatment efficiency of the pond. Method B computes the means of mass loads or EMCs for both inflows and outflows. The method then calculates the mean treatment efficiency using the average load or concentration values.

<u>Method A:</u> This method defines the treatment efficiency of a pond for any pollutant parameter to be

$$Eff_i = \frac{V_{ii}C_{ii} - V_{oi}C_{oi}}{V_{ii}C_{ii}} \times 100\% \qquad [4]$$

where,

Eff_i = treatment efficiency for the i^{th} runoff event,
V_{ii} = volume of inflow from the i^{th} runoff event,
V_{oi} = volume of outflow from the pond for the i^{th} event,
C_{ii} = flow-weighted mean concentrations of inflow for i^{th} runoff event, and
C_{oi} = flow-weighted mean concentrations of outflow for i^{th} runoff event.

In General, C_{ii} and C_{oi} are inflow and outflow EMCs, respectively.

Let $V_{oi} = P\, V_{ii}$, where P is a percentage value less than or equal to 1. Theoretically, the outflow volume should always be less than the inflow volume if there is no groundwater recharges into the pond. The outflow volume is the inflow volume minus the sum of storage change (or increase), infiltration, and other leakage from the pond. Assume $P = 1$, then $V_{oi} = V_{ii}$. In this case, equation [4] is reduced to

$$Eff_i = \frac{C_{ii} - C_{oi}}{C_i} \times 100\%, \qquad [5]$$

Where C is the event mean concentration for the inflow and outflow respectively. This equation provides the minimum estimate of the treatment efficiency for a runoff event. Method A assumes that the treatment efficiency for any runoff event or the term on the left hand side of equation [5] is a random variable that has a normal distribution. The sample mean of this variable is thus an unbiased estimate of the population mean if the size of the sample (or the number of treatment efficiency values) is sufficient. In other words, the treatment efficiency for the pond is computed as the mean of the individual event efficiencies.

The basis of this method is that the values of outflow EMCs are approximately proportional to the values of inflow EMCs. In other words, $\text{EMC}_{oi} = a\,(\text{EMC}_{ii}) + e$, where a is a constant, and e is a random element following an independent, normal distribution. This fact can be identified in the later section. When the EMCs are used to compute treatment efficiency, however, the monitoring should observe if the pond operates properly. The computation of the mean removal efficiency may not be valid if (1) the water does not effectively pass through the pond or filter, (2) there is significant leakage of water from the pond, or (3) a substantial amount of water entering the pond by-passes the monitoring station. Method A can reasonably apply to sedimentation, filtration, or their combination.

__Method B:__ This method assumes that the loads or EMCs of outflows for individual runoff events are independent of the inflow concentrations of the same events. In this case the mean treatment efficiency for a pollutant parameter should be evaluated by comparing the overall loadings or mean EMCs between inflows and outflows for a specific time period. The mean treatment efficiency for a pond can be expressed by the following equation.

$$Eff = \frac{C_i \sum_{j=1}^{n} V_{ij} - C_o \sum_{j=1}^{n} V_{oj}}{C_i \sum_{j=1}^{n} V_{ij}} \times 100\% \qquad [6]$$

where,

V_{ij} = inflow volume for the j^{th} event for a specific monitoring period,
V_{oj} = outflow volume for the j^{th} event for the same monitoring period,
C_i = flow-weighted means of the inflow concentrations for all events, and
C_o = flow-weighted means of the outflow concentrations for all events.

Letting P once again represent the relationship between inflow volume and outflow volume:

$$\sum_{j=1}^{n} V_{ij} = P \sum_{j=1}^{n} V_{oj} ,$$

then equation [6] reduces to,

$$Eff = \frac{C_i - PC_o}{C_i} \times 100\% , \qquad [7]$$

where $P \leq 1$ as defined before. Normally, C_i and C_o are the sample means of the log-normally distributed EMC data (EPA, 1983 and Driscoll, 1986) as identified below:

$$M = T\sqrt{1 + Cv^2} \qquad [8]$$

in which M is C_i or C_o, the sample mean of EMCs, T is an unbiased estimate of median or the geometric mean of EMCs, and Cv is coefficient of variation.

$$Cv = \sqrt{e^{W^2} - 1} , \qquad [9]$$

where w is the standard deviation of the log-transformed data of EMCs.

By estimating the values of C_i and C_o and assuming $P = 1$, equation [7] can be used to compute mean treatment efficiency for a specific pond. Obviously, method B can best be applied to a wet pond such as St. Elmo Retention Basin. Theoretically, the loads or concentrations of outflows from a wet pond during a runoff given event should not be dependent on the inflow concentrations during this event. As indicated later, the outflow EMCs for St. Elmo Pond are not well related to the inflow EMCs of the same events. This method can also apply to sedimentation and filtration basins if the numbers of both inflow and outflow EMCs are sufficiently large.

Overall Removal Efficiency: The overall annual removal efficiency for a pond is the mean treatment efficiency of the pond multiplied by a factor equal or less than 1.0, depending on whether the pond treats all or a portion of the runoff generated from the watershed above the pond. This factor can be determined from a table previously prepared (COA, 1990c). For a specified "capture volume of ½-inch runoff," this table correlates the percent untreated runoff and the percent untreated mass load to the watershed imperviousness. Normally the wet ponds treat all runoff while the sedimentation/filtration systems treat only a portion of the runoff.

4.2 Characterization of Performance for BRP and SEP

This study used both methods A and B to evaluate the treatment efficiencies of BRP and SEP for all conventional pollutant parameters. For BRP, there are not adequate data to compute EMCs for metal parameters, the overall flow volume-weighted means of instantaneous concentrations were used to compute the mean treatment efficiencies. For SEP, the flow data associated with metal concentration measurements has not been analyzed, the means of median instantaneous concentrations for all events were used to compute the treatment efficiencies.

4.2.1 Characterization of Performance for Barton Ridge Plaza Ponds

The COA has continuously monitored BRP since September 1993. Between September 1993 and September 1995, the City staff sampled 3 of the 4 monitoring stations at the pond approximately 22 times. The staff also sampled 5 times at the overflow station. The flow monitoring during 1995 recorded runoff discharges through the pond for 37 times. Table 6 provides data analyzed for BRP, including event rainfall, inflow to the pond, and outflow and overflow (or diverted runoff) from the pond. This table does not show flow data of September 1993 to December 1994. The mass balance of flow for this early period cannot be reasonably verified due to significant leaks from the ponds and due to unexpected runoff entering the filtration pond from an adjacent area. As a result of these problems, the structure was fully repaired during the period of December 1994 to January 1995.

The "storage change" in Table 6 identifies the portion of runoff that remains in the sedimentation and filtration ponds after a runoff event. About 2 to 4 inches of water and sediment are usually stored below the holes of the pipe riser in the sedimentation pond. The 18-inch sand bed in the filtration basin also holds a portion of runoff after each runoff event. The fine sand has a field capacity of about 7 percent. The "storage change" was estimated to be about 0.07 inch and was assumed to be part of the outflow. This minor portion of outflow evaporates during the dry period between runoff events.

Figures 36-38 exhibit the relationships among outflow, inflow, and rainfall depths for all runoff events. The outflow quantity cannot exactly match the inflow quantity for three reasons. First, flow measurement error are estimated to be up to 10 percent at both inflow and outflow stations. Second, the monitoring staff observed a small leak from the filtration pond near the outlet. Third, during a few runoff events, the water spilled over the retaining wall from the filtration pond. Nevertheless, the overall mass balance of flow for a 9-month period is reasonable. The runoff to rainfall depth ratio (or the runoff coefficient, RV) for this period is about 0.77. The total outflow is about 92 percent of the total runoff or inflow, presenting some error in flow accounting. It is estimated that the leakage and spills from the filtration pond may account for 3 percent of the inflow. The flow measurement errors account for the remaining problem.

EMCs were computed for inflow and outflow stations of BRP using flow rate and instantaneous concentration data (as shown in Appendixes A and D). Table 7 presents the means of EMCs derived from Equations [8] and [9] for these stations. Appendix C1 shows the details of EMC values for BRP for all pollutant parameters. The average number of EMCs for the BRP stations is approximately 10 -16, although the overall number of sampled events is about 22. The average number of the paired EMCs for inflow and filtration-outflow and for inflow and sedimentation-outflow is "eight."

The study evaluated the mean treatment and removal efficiencies for the sedimentation pond and the overall sand filtration system using method A. Tables 8-9 present the results of treatment and removal efficiencies based on the paired comparisons of EMCs. The computation assumes that the outflow volume equals inflow volume for each runoff event. In reality, the overall quantity of inflow for each event is less or equal than that of inflow. Table 10 shows the inflow and outflow quantities corresponding to the events of the seven paired-EMCs. For the events which occurred before January 1995, there were significant leaks of inflows from the pond system as described before. Since January 1995, the mass balance accounting of flows has been fairly accurate. The water leaks should not have impacted the values of the EMCs. The treatment efficiencies or the ratios of outflow EMCs to inflow EMCs before and after January 1995 are consistent as indicated by the data (Figure 39 and Appendix C1).

The treatment and removal efficiencies of the metal parameters were estimated using the overall flow volume-weighted means of instantaneous concentrations because of insufficient EMC data. Table 11 provides values of these averages for BRP. The grant study derived these values using all of the flow and instantaneous concentration data collected from the monitoring project (Appendixes A and F). The study divided the total runoff of each hydrograph into two portions, the first 33 percent of runoff volume and the next 67 percent of runoff volume.

Table 6

Data of Rainfall, Inflow, and Outflow for Barton Ridge Pond

No. of Storms	Storm ID	Starting Date (BRI)	Starting Time (BRI)	Ending Date (BRI)	Ending Time (BRI)	Site Rainfall (inch)	FEWS 1020 Rainfall (inch)	FEWS 1210 Rainfall (inch)	FEWS 1100 Rainfall (inch)	BRI* Inflow (inch)	BRE* Outflow (inch)	Storage Change (inch)	BRO* Overflow (inch)
1	950112A	1/12/95	17:46	1/13/95	0:43	0.65	0.51	0.67	0.75	0.48	0.41	0.07	-
2	950125A	1/25/95	20:00	1/26/95	15:59	0.20	0.20	0.23	0.12	0.06	-	-	-
3	950212A	2/12/95	23:31	2/14/95	22:45	0.19	0.15	0.24	0.19	0.06	-	-	-
4	950224A	2/24/95	11:30	2/24/95	20:29	0.27	0.40	0.27	0.48	0.12	0.02	0.07	-
5	950225B	2/25/95	12:46	2/25/95	23:45	0.51	0.67	0.59	0.59	0.34	0.27	-	-
6	950301A	3/1/95	22:00	3/3/95	13:57	0.17	0.16	0.20	0.28	0.05	-	-	-
7	950307A	3/7/95	1:01	3/7/95	9:15	0.30	0.24	0.43	0.28	0.18	0.03	0.07	-
8	950312A	3/12/95	22:31	3/13/95	12:30	1.70	2.48	3.10	2.09	1.46	0.83	0.07	0.56**
9	950315A	3/15/95	14:31	3/16/95	4:28	0.45	0.43	0.40	0.39	0.26	0.18	0.07	-
10	950329A	3/29/95	5:01	3/29/95	14:59	0.06	0.16	-	0.08	0.01	-	-	-
11	950331A	3/31/95	3:21	3/31/95	13:20	0.08	0.07	0.08	0.12	0.02	-	-	-
12	950403A	4/3/95	14:21	4/4/95	0:20	0.13	-	-	-	0.04	0.0042	-	-
13	950418A	4/18/95	0:01	4/18/95	12:00	0.34	0.43	0.36	0.43	0.14	0.01	0.07	-
14	950419A	4/19/95	7:00	4/19/95	17:59	0.16	0.08	0.15	0.20	0.07	-	-	-
15	950420A	4/20/95	0:00	4/20/95	8:29	0.69	0.91	0.71	0.99	0.58	0.64	-	-
16	950422A	4/22/95	15:00	4/23/95	0:00	0.20	0.20	0.20	0.47	0.09	0.03	0.07	-
17	950506A	5/6/95	9:45	5/6/95	16:59	0.10	-	0.12	0.08	0.06	-	-	-
18	950508A	5/8/95	1:21	5/8/95	12:19	2.06	2.05	2.36	2.52	1.64	0.95	0.07	0.62**
19	950518A	5/18/95	2:00	5/18/95	9:58	0.51	0.39	0.27	0.47	0.32	0.28	0.07	-
20	950527A	5/27/95	2:46	5/27/95	12:44	0.18	0.20	0.24	0.20	0.06	-	-	-
21	950529A	5/29/95	2:00	5/29/95	11:58	2.40	2.20	3.34	2.36	2.06	1.81	0.07	0.18**
22	950530A	5/30/95	0:31	5/30/95	10:20	2.06	-	-	-	1.94	-	-	1.94**
23	950530B	5/30/95	10:21	5/31/95	1:20	1.00	-	-	-	0.95	-	-	0.95**
24	950531A	5/31/95	21:41	6/1/95	6:39	0.99	0.98	1.22	0.95	0.90	-	-	0.11
25	950611A	6/11/95	0:41	6/11/95	11:40	1.58	1.61	2.13	1.42	1.29	1.01	0.07	0.21**
26	950628A	6/28/95	21:30	6/29/95	21:59	0.66	0.91	0.63	0.67	0.46	0.21	0.07	-
27	950706A	7/6/95	8:21	7/6/95	22:59	0.23	0.16	0.19	-	0.13	-	-	-
28	950730A	7/30/95	20:41	7/31/95	4:59	1.36	1.02	1.70	1.45	1.11	1.23	0.07	-
29	950731A	7/31/95	18:21	8/1/95	4:20	0.42	0.39	0.67	0.60	0.31	-	-	-
30	950801A	8/1/95	17:41	8/2/95	2:38	0.46	0.55	0.82	0.47	0.39	-	-	-
31	950812A	8/12/95	14:11	8/12/95	20:40	0.10	0.12	0.08	-	0.06	0.02	0.07	-
32	950823A	8/23/95	15:40	8/23/95	22:09	0.16	0.24	0.12	-	0.08	-	-	-
33	950907A	9/7/95	19:40	9/8/95	2:10	0.90	0.86	1.57	0.67	0.69	0.34	0.07	0.17
34	950913A	9/13/95	21:00	9/14/95	3:59	0.37	0.12	0.24	-	0.18	0.14	0.07	-
35	950920A	9/20/95	3:31	9/20/95	17:29	0.92	0.87	0.98	0.71	0.73	0.58	0.07	-
36	950921A	9/21/95	11:31	9/21/95	21:30	0.23	0.19	0.32	-	0.16	-	-	-
37	950921B	9/21/95	22:00	9/22/95	11:59	0.11	-	-	-	0.07	-	-	-

* BRI, BRE, and BRO represent monitoring sites of inflow, outflow, and overflow.

** Estimated from inflow values.

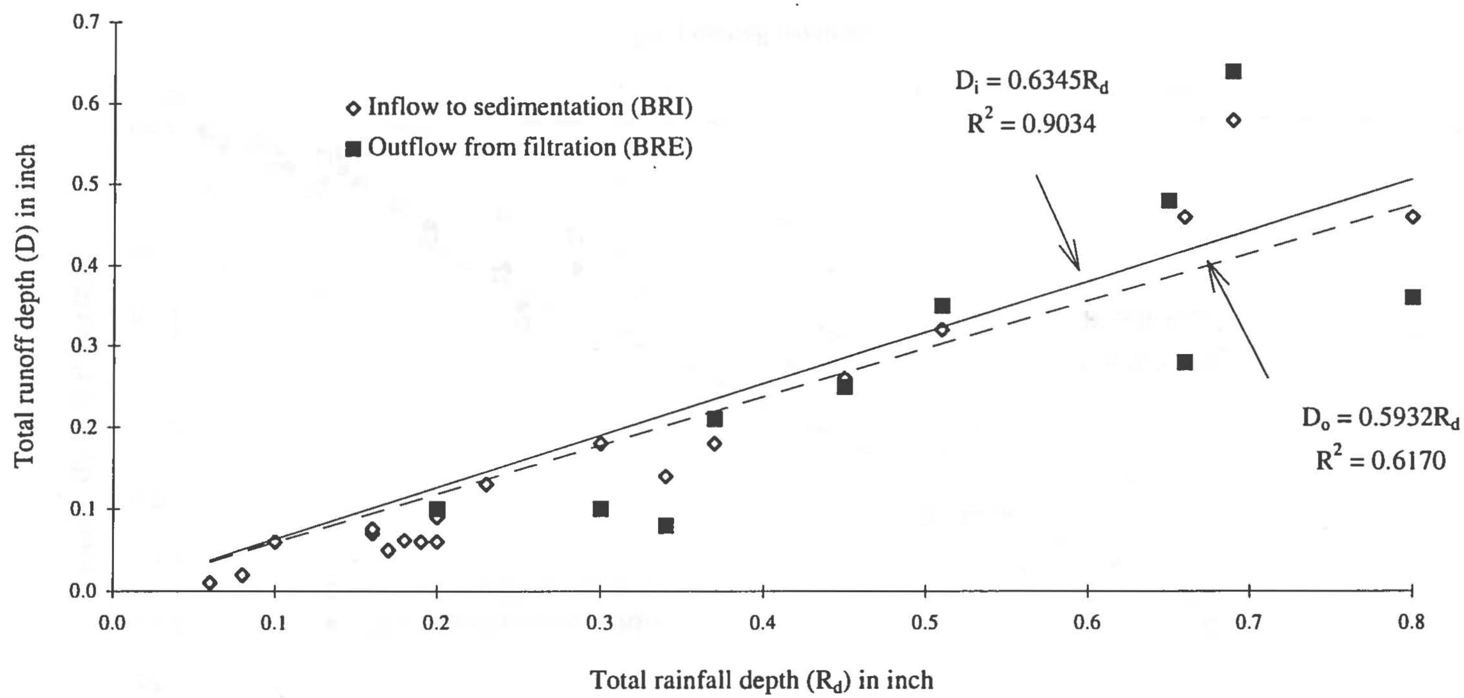


Figure 36. Relationships of inflow (BRI) and outflow (BRE) versus rainfall for Barton Ridge Plaza Ponds (overflow excluded)

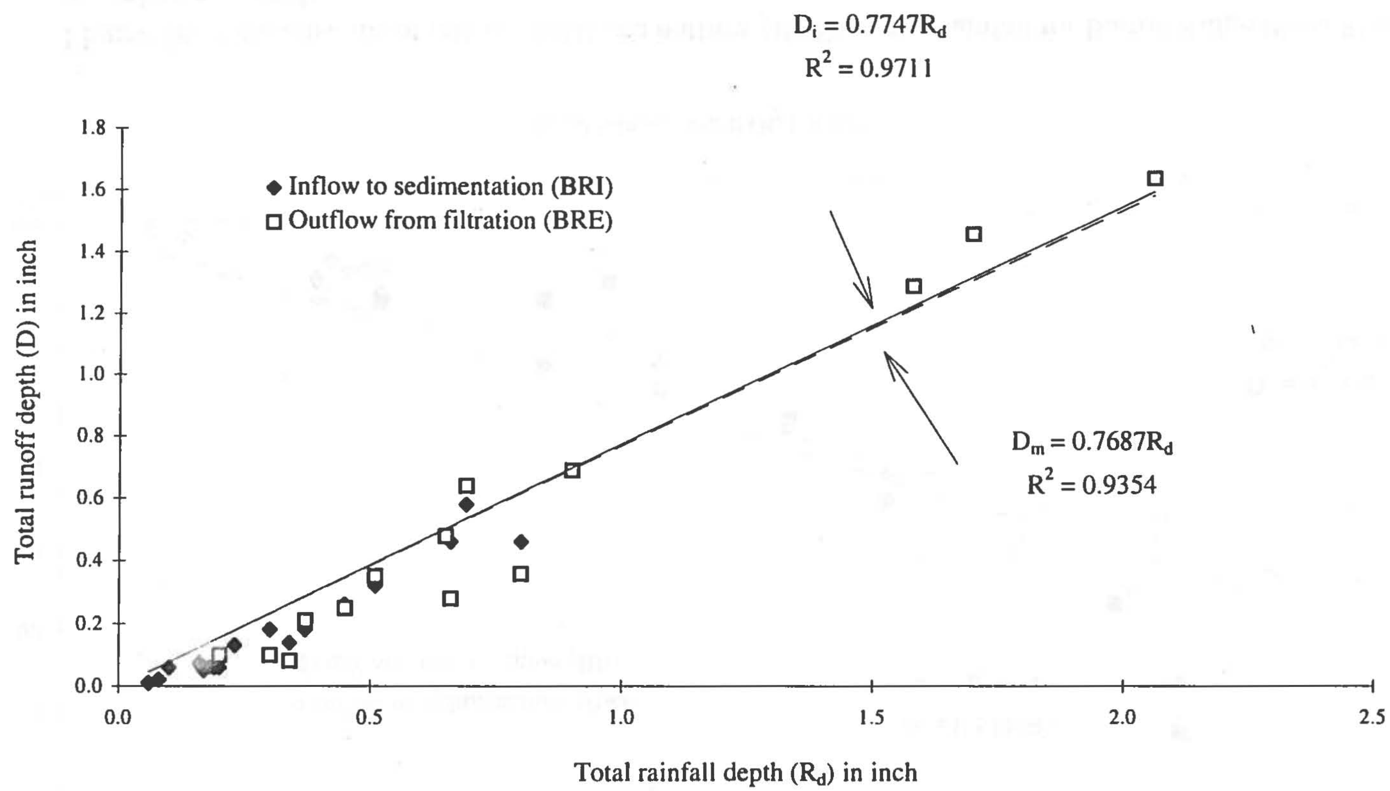


Figure 37. Relationships of inflow (BRI) and outflow (BRE) versus rainfall for Barton Ridge Plaza Ponds (overflow included)

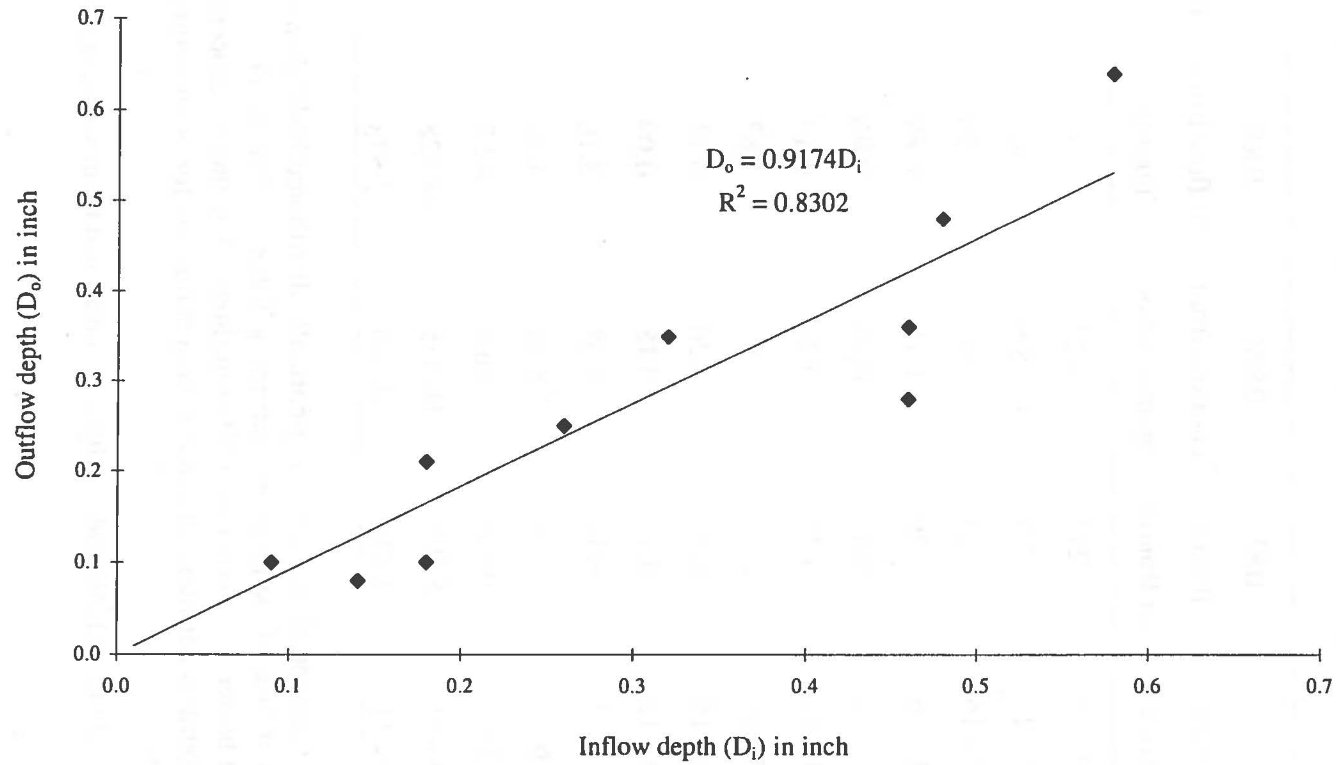


Figure 38. Relationship of outflow (BRE) versus inflow (BRI) for Barton Ridge Plaza Ponds (overflow excluded)

Table 7

Averages of Event Mean Concentrations (EMCs) for Monitoring Stations at Barton Ridge Plaza Ponds

Pollutant* Parameters	No. of Storms	BRI Inflow or Runoff	BRM Outflow from Sedimentation	BRE Outflow from Filtration	BRO Overflow Spill**
TSS	10 - 16	273	123	32	20
BOD	6 - 15	12.7	8.9	4.7	3.0
COD	11 - 16	77	41	25	15
TKN	11 - 16	1.76	1.18	0.89	0.69
NO_2+NO_3	11 - 16	0.67	0.50	0.96	0.55
NH_3	11 - 16	0.29	0.24	0.14	0.14
TN	11 - 16	2.43	1.64	1.83	1.24
TP	11 - 16	0.37	0.20	0.11	0.04
DP	3 - 12	0.14	0.18	0.09	-
Cu	6 - 7	9.33	9.88	5.16	-
Pb	6 - 7	17.08	8.35	4.32	-
Zn	3 - 7	103.5	36.5	42.7	-
Fe. Col.	4 - 11	5,695	16,635	18,528	-
Fe. Strp	5 - 11	12,576	4,340	2,573	-

* Averages of EMCs are sample means of log-normally distributed EMC data as explained in the text (text of explanation concerning Table 7). The unit of concentrations for bacteria is colonies per 100 milliliters. The unit of concentrations for metals is micrograms per liter. The unit of concentrations for other parameters is milligrams per liter.

** There is no EMC data for this station. Values are mean instantaneous concentrations.

Table 8

Overall Removal Efficiency of Barton Ridge Plaza Ponds Based on a Paired Comparison of Inflow and Outflow Event Mean Concentrations

	BRI Inflow	BRE Outflow	Pond System Treatment Efficiency (%)	t-Test p > t	Estimated Annual ** Removal Efficiency (%)
Site Name	Barton Ridge Plaza Pond				
Land-Use Type	Commercial				
Drainage Area	2.95 acres				
Impervious Cover	81%				
No. of Paired Event Mean Conc.	8	8			
Average of Event Mean Conc. *	EMC_i	EMC_e			
Pollutant Parameters :					
TSS	273	32	89	0.0000	71
VSS	37	4	87	0.0000	70
BOD	12.7	4.7	51	0.0033	41
COD	77	25	55	0.0001	44
TOC	7	7	-4	0.2823	-3
NO2 + NO3	0.67	0.96	-76	0.0086	-61
TKN	1.76	0.89	50	0.0004	40
NH3	0.29	0.14	53	0.0010	43
TN	2.43	1.83	17	0.0232	14
TP	0.37	0.11	59	0.0009	47
DP	0.14	0.09	3	n. s.	2
Fe. Col.	5,695	18,528	-85	0.2796	-68
Fe. Strep.	12,576	2,573	69	0.0224	55

* The average of event mean concentrations for each pollutant parameter is the overall mean of individual inflow or outflow EMC values. The overall mean is the sample mean of log-normally distributed EMC data (as explained in the text). This table shows the treatment efficiency based on paired comparison, instead of the comparison of overall means. The unit of concentrations for bacteria is colonies per 100 milliliters. The unit of concentrations for other parameters is milligrams per liter.

** The annual removal efficiency is the system treatment efficiency multiplied by a factor of 0.80. It is estimated that on an annual basis, about 30 percent of runoff will overflow and bypass the ponds without being treated by the system. According to a previous study ("First Flush" Study; COA, 1990b), the untreated runoff contains about 20 percent of the total annual load.

Table 9

Removal Efficiency of Barton Ridge Plaza Sedimentation Pond Based on a Paired Comparison of Inflow and Outflow Event Mean Concentrations

	BRI Inflow to Sedimentation	BRM Outflow from Sedimentation	Sedimentation Pond Treatment Efficiency (%)	t-Test $p > t$	Estimated Annual ** Removal Efficiency (%)
Site Name	Barton Ridge Plaza Pond				
Land-Use Type	Commercial				
Drainage Area	2.95 acres				
Impervious Cover	81%				
No. of Paired Event Mean Conc.	8	8			
Average of Event Mean Conc. *	EMC_i	EMC_m			
Pollutant Parameters :					
TSS	273	123	57	0.0001	46
VSS	39	16	55	0.0002	44
BOD	12.7	8.9	33	0.0738	26
COD	77	41	34	0.0045	27
TOC	7	8	-19	0.4856	-15
NO2 + NO3	0.67	0.50	3	0.2397	3
TKN	1.76	1.18	33	0.0082	26
NH3	0.29	0.24	7	0.1903	6
TN	2.43	1.64	28	0.0139	22
TP	0.37	0.20	49	0.0013	39
DP	0.14	0.18	23	n. s.	19
Fe. Col.	5,695	16,635	-63	0.0247	-51
Fe. Strep.	12,576	4,340	-35	0.4409	-28

* The average of event mean concentrations for each pollutant parameter is the overall mean of individual inflow or outflow EMC values. The overall mean is the sample mean of log-normally distributed EMC data (as explained in the text). This table shows the treatment efficiency based on paired comparison, instead of the comparison of overall means. The unit of concentrations for bacteria is colonies per 100 milliliters. The unit of concentrations for other parameters is milligrams per liter.

** The annual removal efficiency is the system treatment efficiency multiplied by a factor of 0.80. It is estimated that on an annual basis, about 30 percent of runoff will overflow and bypass the ponds without being treated by the system. According to a previous study ("First Flush" Study; COA, 1990b), the untreated runoff contains about 20 percent of the total annual load.

Table 10

Accounting of Flows Passing through Barton Ridge Pond for the events of Paired EMCs

Storm ID	Rainfall (inch)	Inflow (inch)	Outflow (inch)	Overflow (inch)	Storage (inch)
930831A*	0.82	0.56	0.002	0.00	0.07
940513A*	1.23	0.70	0.13	0.28	0.07
940603A*	0.60	0.46	0.17	0.00	0.07
940613A*	0.97	0.72	0.22	0.00	0.07
950112A	0.65	0.48	0.41	0.00	0.05
950312A	1.70	1.46	0.83	0.56	0.07
950403A	0.13	0.04	0.0042	0.00	0.03
950508A	2.06	1.64	0.95	0.62	0.07

* Significant leaks of water from the pond during the period before January 1995. Nevertheless, the leaks did not impact the treatment of the remaining water that passed through the pond system. The treatment efficiencies of the system after ponds repair conform with those before the repair. (Ponds repaired in December 1994).

Table 11

Values of Flow Volume-Weighted Means of Instantaneous Concentrations for Barton Ridge Plaza Ponds

Pollutant Parameter	BRI Concentrations of Inflow to Sedimentation Pond			BRM Concentrations of Outflow from Sedimentation Pond			BRE Concentrations of Outflow from Filtration Pond		
	Number of Observations	Mean	Median	Number of Observations	Mean	Median	Number of Observations	Mean	Median
TSS	119	397*	158*	79	110*	59*	111	16*	5*
VSS	119	57.7	28	79	16.2	10	111	3.3	2
BOD	109	9.5	8	66	11.5	6	94	2.6	3
COD	125	76	57	88	43	35	125	17	18
TKN	125	1.63	1.60	88	1.08	0.97	125	0.57	0.60
NO23	124	0.74	0.59	88	0.51	0.41	125	0.73	0.59
NH3	125	0.24	0.23	88	0.21	0.18	125	0.10	0.09
TN	124	2.39	2.21	88	1.59	1.40	125	1.31	1.27
TP	125	0.37	0.28	88	0.18	0.16	125	0.07	0.08
DP	89	0.13	0.10	41	0.23	0.10	65	0.05	0.06
TOC	100	11.30	6.49	61	12.50	7.47	90	5.00	4.08
CU	55	10.200	8.000	52	9.590	8.000	41	2.900	4.000
CD	55	0.871	0.500	53	0.958	1.000	41	0.492	0.500
PB	55	16.900	11.000	53	11.100	7.000	40	2.310	2.000
ZN	44	92.500	50.000	50	47.800	40.000	36	22.600	40.000
FE. COL.	78	26300	2000	40	37700	9900	71	11200	1000
FE. STRP.	82	19500	4350	46	4340	2730	71	3150	1000

* The unit of concentrations for bacteria is colonies per 100 milliliters. The unit of concentrations for other parameters is milligrams per liter.

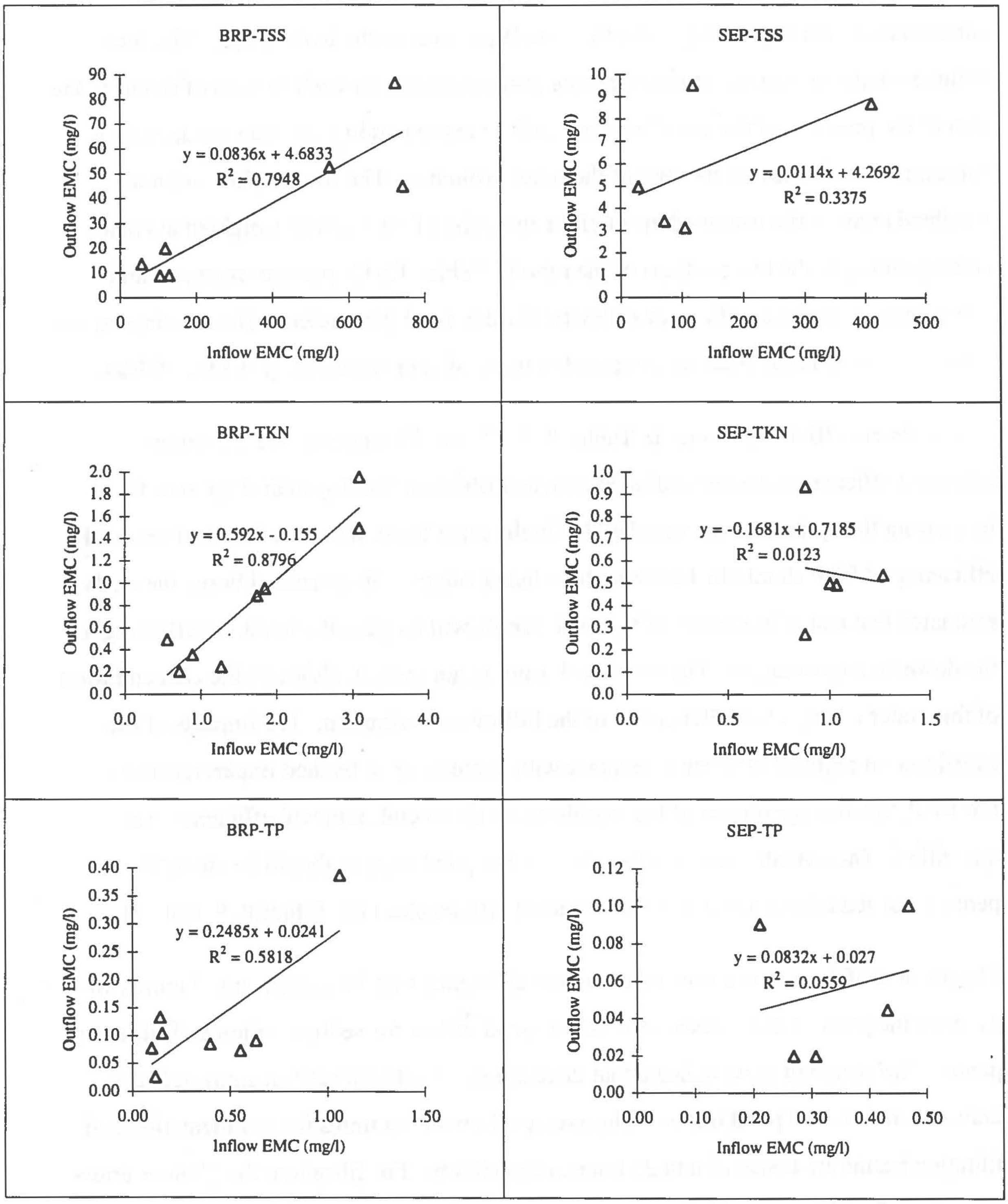


Figure 39 . Relationships of Outflow EMCs Versus Inflow EMCs for Barton Ridge Plaza Sand Filtration and St. Elmo Wet Pond

For each hydrograph, project staff further computed the averages of instantaneous concentrations corresponding to the two runoff portions of the hydrograph. The flow volume-weighted average of instantaneous concentrations for each portion of runoff is the sum of the products of the runoff volume and the corresponding average instantaneous concentration, divided by the sum of the runoff volumes. The overall flow volume-weighted mean is the weighted mean of the individual flow volume-weighted averages corresponding to the two portions of the runoff. Tables 12-13 present treatment and overall annual removal efficiency estimates for the metal parameters. These estimates are considered to be reasonable, as compared to those of a previous study (COA, 1990a).

The treatment efficiency values in Tables 8, 9, 12, and 13 represent the minimum treatment efficiencies for the sedimentation and filtration pond system if the runoff by-passing the system is not considered. On the other hand, the overall annual removal efficiency of BRP should be less than these listed values. On an annual basis, the study estimated that about 30 percent of the total runoff will by-pass the pond, overflowing to the downstream detention. The by-passed water is not treated, although the concentration of this water is only about 50 percent of the inflow concentration. The impacts of the overflows on removal efficiency decrease with decreasing watershed imperviousness. For BRP, the average impact of the overflows on the overall removal efficiency was quantified. The overall removal efficiency for the pond system should be about 20 percent less than those listed as pond treatment efficiencies (see Tables 8, 9, and 12).

The impacts of draw-down time on treatment efficiency may be significant. Figures 40-41 show the plots of draw-down time versus pond inflow for sedimentation and filtration ponds. The scattered plots indicate that there are no significant relationships between draw-down time and pond inflow. The average draw-down times for sedimentation and filtration basins are about 13 and 25 hours, respectively. For filtration, the 25 hour draw-down time for filtration is likely appropriate, generally complying with the original design of the pond. The draw-down time for sedimentation may not be sufficient for the particulate matter to settle. On the other hand, however, an increase of draw-down time by reducing the size of holes on riser pipes may create drain clogging problems.

Table 12

Overall Removal Efficiency of Barton Ridge Plaza Ponds Based on a Comparison of Flow Volume Weighted Means of Instantaneous Concentrations Between Inflows and Outflows

	BRI Inflow	BRE Outflow		
Site Name	Barton Ridge Plaza Pond			
Land-Use Type	Commercial			
Drainage Area	2.95 acres			
Impervious Cover	81%			
No. of Concentration Values	*	*	**Pond System Treatment Efficiency (%)**	**Estimated Annual Removal Efficiency (%)**
Flow Volume Weighted Instantaneous Conc. **	$BRIC_i$	$BRIC_e$		
Pollutant Parameters :				
Cd	0.87	0.49	44	35
Cu	10.20	2.90	72	57
Pb	16.90	2.31	86	69
Zn	92.50	22.60	76	60

* Number of concentration values varies from 40 to 130 depending on stations and pollutant parameters.

** The unit of concentrations for bacteria is colonies per 100 milliliters. The unit of concentrations for metals is micrograms per liter. The unit of concentrations for other parameters is milligrams per liter.

Table 13

Removal Efficiency of Barton Ridge Plaza Sedimentation Pond Based on a Comparison of Flow Volume Weighted Means of Instantaneous Concentrations Between Inflows and Outflows

	BRI Inflow	BRM Outflow		
Site Name	Barton Ridge Plaza Pond			
Land-Use Type	Commercial			
Drainage Area	2.95 acres			
Impervious Cover	81%			
No. of Concentration Values	*	*	**Sedimentation Pond Treatment Efficiency (%)**	**Estimated Annual Removal Efficiency (%)**
Flow Volume Weighted Instantaneous Conc. **	$BRIC_i$	$BRIC_m$		
Pollutant Parameters :				
Cd	0.87	0.96	-10	-8
Cu	10.20	9.59	6	5
Pb	16.90	11.10	34	27
Zn	92.50	47.80	48	38

* Number of concentration values varies from 40 to 130 depending on stations and pollutant parameters.

** The unit of concentrations for bacteria is colonies per 100 milliliters. The unit of concentrations for metals is micrograms per liter. The unit of concentrations for other parameters is milligrams per liter.

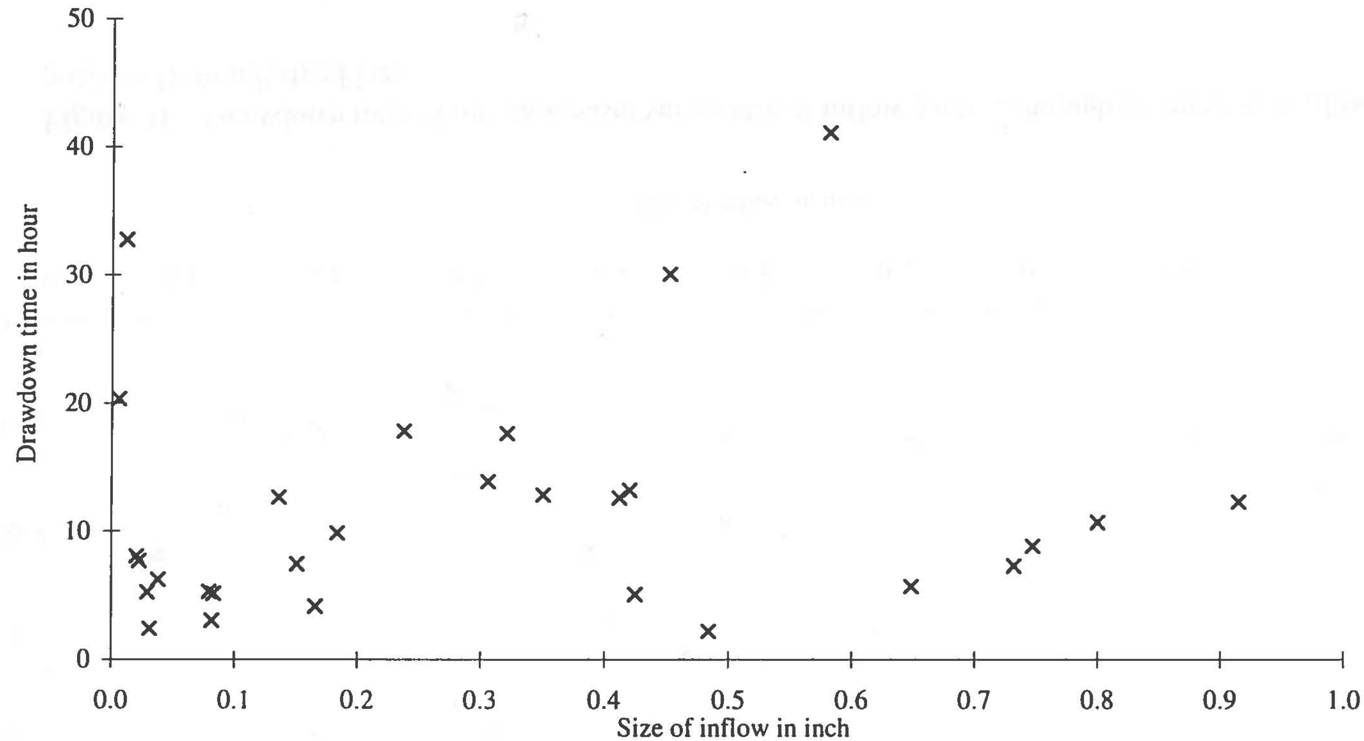


Figure 40. Drawdown time of sedimentation pond versus size of inflow passing through the sedimentation/filtration ponds (excluding the overflow by-pass the ponds)

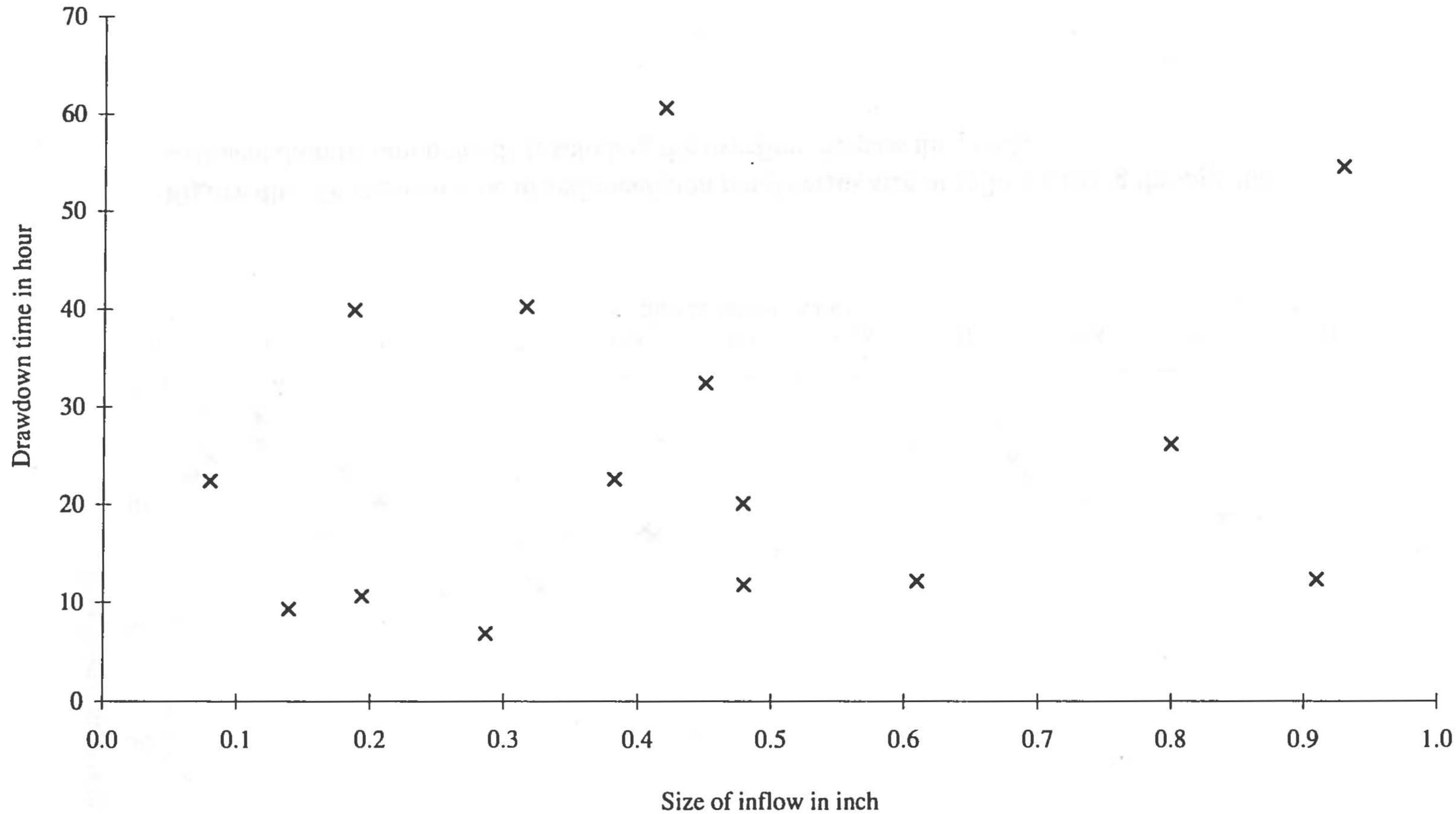


Figure 41. Drawdown time of filtration basin versus size of inflow passing through sedimentation/filtration ponds at Barton Ridge Plaza

The design of Barton Ridge Plaza Ponds approximately follows the COA's design guidelines on water quality control basins. The performance of the pond generally complies with the desired functions of the design. Through stormwater monitoring and assessment, it was found that the performance of the pond is fairly effective for controlling NPS pollution. The draw-down of water in the sedimentation pond is faster than that of the original design. This deviation, however, can help reduce clogging in the sedimentation pond outlet structure. The sedimentation pond has served its main purpose of slowing down the flow to filtration and preventing large quantities of sediment from entering the filtration basin. On the other hand, this faster movement of water from sedimentation has caused minor spills over the retaining wall of the sand filtration pond.

Another reason for the spills from the filtration basin is the small size of the sand bed surface, although there is an additional, non-filtering area in the filtration pond. The ratio of the sand bed surface area to the contributing drainage area is about 0.003. An increase of the ratio from 0.003 to 0.005 can increase the speed of filtration and can probably increase the mean treatment efficiency of the pond system.

The ponds experienced a major repair and maintenance job in January 1995. This job sealed significant cracks along the edges of both sedimentation and filtration ponds. It also replaced the sand bed and the underdrain system. The 4-inch underdrain pipes had caused drain clogging problems and were replaced with the 6-inch pipes. Subsequently the ponds have been performing for a 24-month period without problems. It is important that a sand filtration system be inspected frequently during the first year of implementation. After the first year, an evaluation regarding further maintenance should be conducted periodically. A sand filtration system with splitter box, full sedimentation pre-treatment, and sufficient filtration area should be an effective structural BMP for NPS pollution control.

4.2.2 Characterization of Performance for St. Elmo Pond

The COA has continuously monitored SEP since April 1995. Between April 1995 and September 1995, the City staff sampled runoff water of all 3 stations for about 12 runoff events. Flow data was recorded for 21 runoff events.

Data from these runoff events, including rainfall, east-side (SWI) inflow, west-side (SWJ) inflow, storage change, and wet pond (SWE) outflows are presented in Table 14. The monitoring missed some flow measurements because of equipment malfunctions and backwater conditions. These missing values of inflows were filled in by correlating the runoff between two inflow stations (as shown in Table 14). The backwaters from SEP often impacted the conditions of runoff inflows. At the east-side channel, the ponded water can slightly impact the measurements of inflow concentration due to dilution. The mixing of the ponded water with the inflow at the west-side drain is more serious.

The water quality conditions of inflow to the pond can best be represented by the concentrations of the east-side inflows. The east-side watershed constitutes the majority of the drainage area above the pond. The watersheds at both sides have similar basin characteristics. Appendix B provides the concentration data for all monitoring stations at SEP. Appendix G presents hydrographs and pollutographs for these stations.

Figures 42-45 exhibit relationships among rainfall, inflow, and outflow for all runoff events. The runoff to rainfall depth ratios (runoff coefficients, Rv's) for both east-side and west-side watersheds are 62 and 71 percent, respectively. The runoff coefficient for the entire watershed is 0.60, corresponding to a watershed imperviousness of 66 percent. The total outflow from the wet pond during a runoff event is about 71 percent of the total inflow. The storage increase during an event accounts for 18 percent of the total inflow.

The mass balance accounting of inflow-outflow for all runoff events indicates that there is about 11 percent of inflow not accounted for. This problem can be contributed to some errors in the flow measurement and the evaluation of storage change. As described earlier, the monitoring at each of the inflow stations may have a flow measurement error

Table 14

Data of Rainfall, Runoff, Inflow, and Outflow for St. Elmo Wet Pond

No. of Storms	Storm ID	Site Rainfall (Inch)	FEWS 810 Rainfall (Inch)	FEWS 830 Rainfall (Inch)	FEWS 910 Rainfall (Inch)	SWI* Runoff (Inch)	SWJ Runoff (Inch)	SWIJ Runoff (Inch)	SWTI Total Inflow (Inch)	Storage Change (Inch)	SWE Outflow (Inch)
1	950405A	0.59	1.03	0.71	1.03	**0.37****	0.43	0.22	0.35	0.15	0.17
2	950418A	0.48	-	0.59	0.52	0.40	**0.46**	0.18	0.37	-	-
3	950420A	0.61	-	0.63	0.67	0.54	**0.62**	0.23	0.50	0.31	0.00
4	950420B	-	0.04	0.04	0.02	0.02	**0.03**	0.00	0.02	-	-
5	950422A	0.29	0.24	0.2	0.24	0.13	**0.15**	0.11	0.13	-	-
6	950508A	1.85	1.97	1.5	2.16	**1.12**	1.30	0.68	1.08	0.28	0.68
7	950518A	0.26	0.55	0.35	0.24	0.10	0.20	0.10	0.12	0.11	0.00
8	950524A	0.24	0.27	0.24	0.23	0.08	0.17	0.09	0.10	0.09	0.00
9	950527A	0.09	0.12	0.08	0.16	0.03	**0.04**	0.03	0.03	0.03	0.00
10	950529A	1.72	2.48	2.09	2.4	1.16	1.21	0.64	1.08	0.14	0.85
11	950530A	1.39	1.38	0.98	1.34	0.85	1.01	0.51	0.82	0.00	0.71
12	950530B	1.22	1.26	0.98	0.87	0.82	**0.95**	0.45	0.78	0.00	0.58
13	950531A	0.97	1.1	0.95	0.9	0.64	**0.75**	0.36	0.61	0.00	0.60
14	950611A	1.35	1.66	1.38	1.54	0.74	**0.86**	0.50	0.72	0.15	0.55
15	950628A	0.82	0.98	0.9	1.1	**0.49**	0.57	0.30	0.48	0.36	0.00
16	950706A	0.29	0.39	0.32	0.43	**0.17**	0.20	0.11	0.16	0.12	0.00
17	950823A	0.5	-	0.39	0.44	0.23	**0.27**	0.19	0.23	-	-
18	950830A	0.23	-	0.12	0.15	0.07	0.17	0.09	0.10	0.08	0.00
19	950907A	2.06	-	1.85	1.1	**1.26**	1.46	0.76	1.21	0.34	0.71
20	950920A	0.74	-	0.47	0.83	0.33	0.55	0.27	0.37	0.11	0.22
21	950921A	0.19	-	0.2	0.24	0.08	0.13	0.07	0.09	0.00	0.09

* SWI, SWJ, SWIJ, and SWE represent monitoring sites of east-side inflow, west-side inflow, intervening area inflow, and pond outflow, respectively.
** Bold numbers are runoff values of SWI or SWJ estimated from the measured runoffs of SWJ or SWI.

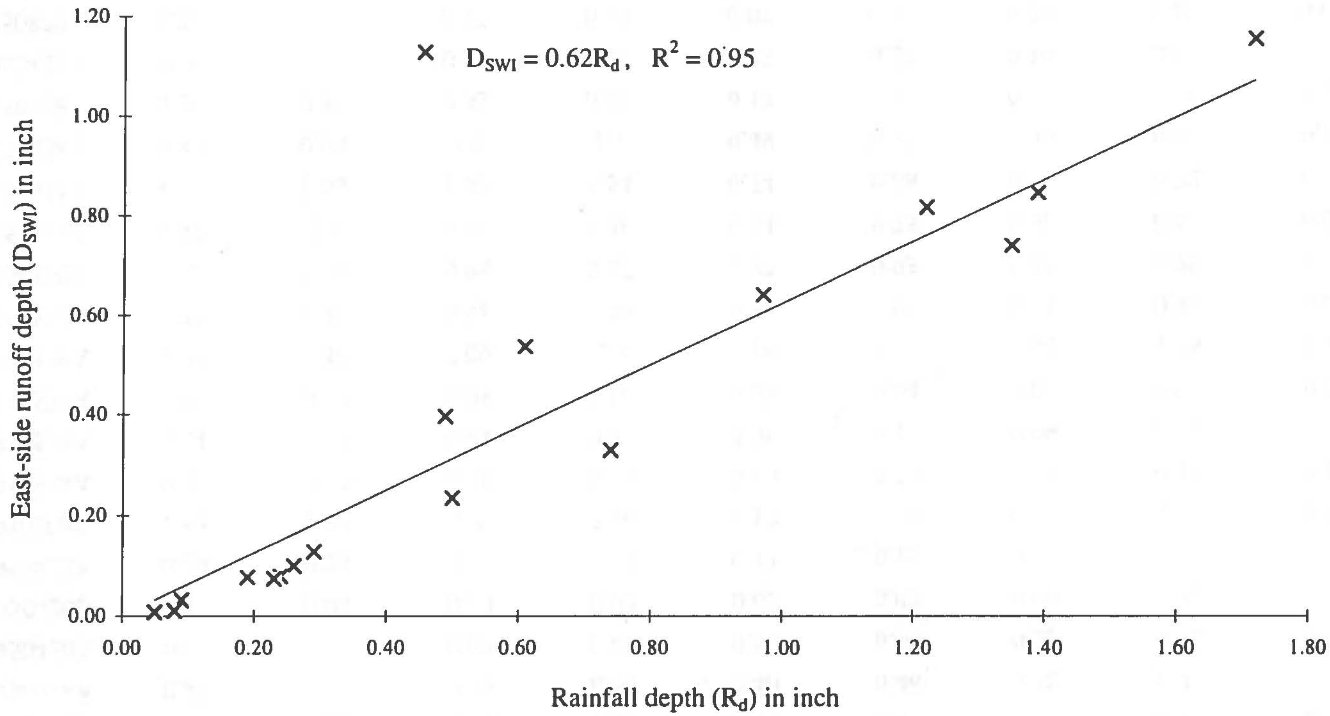


Figure 42. Relationship of east-side inflow depth versus rainfall depth for St. Elmo Wet Pond

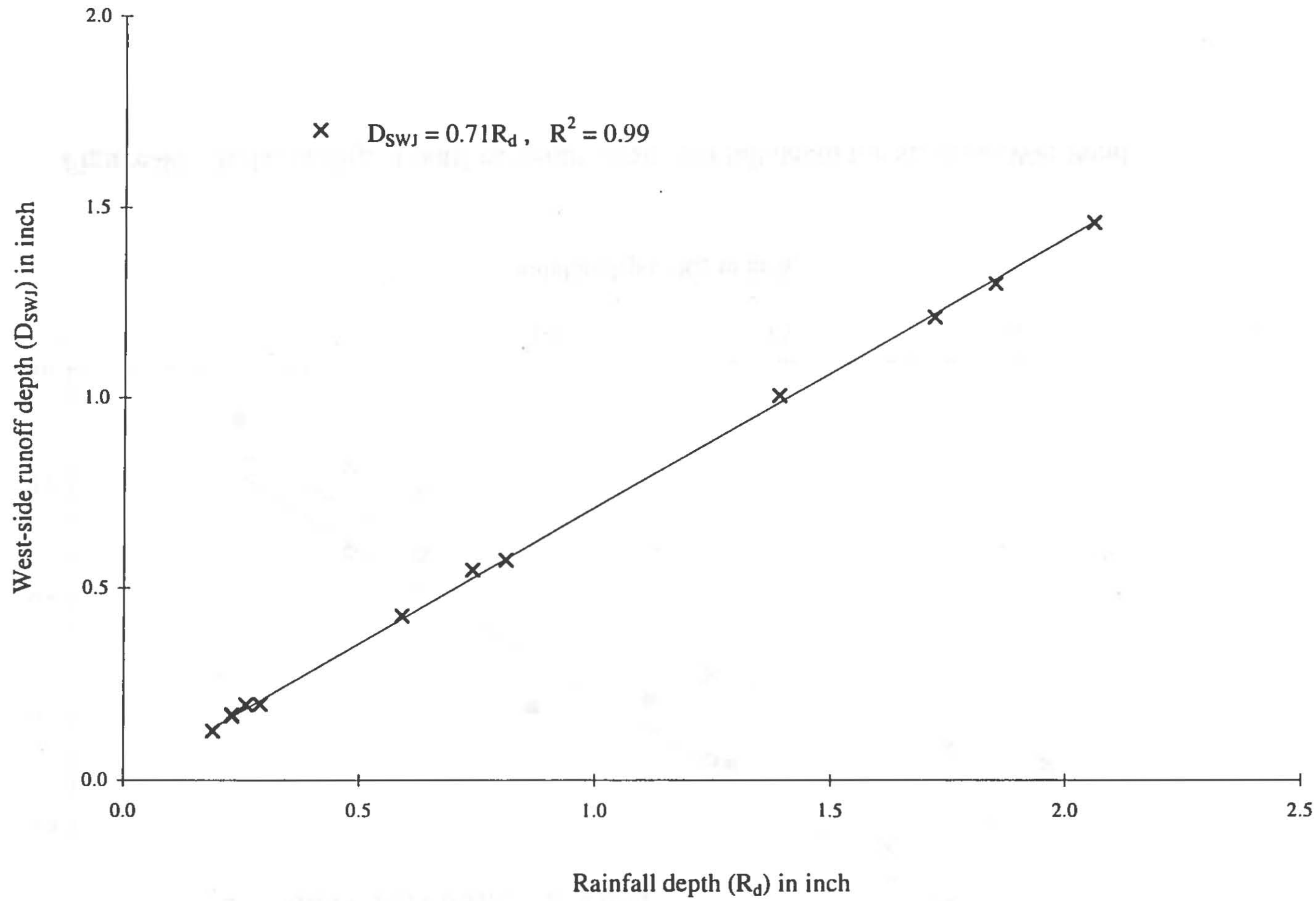


Figure 43. Relationship of west-side inflow depth versus rainfall depth for St. Elmo Wet Pond

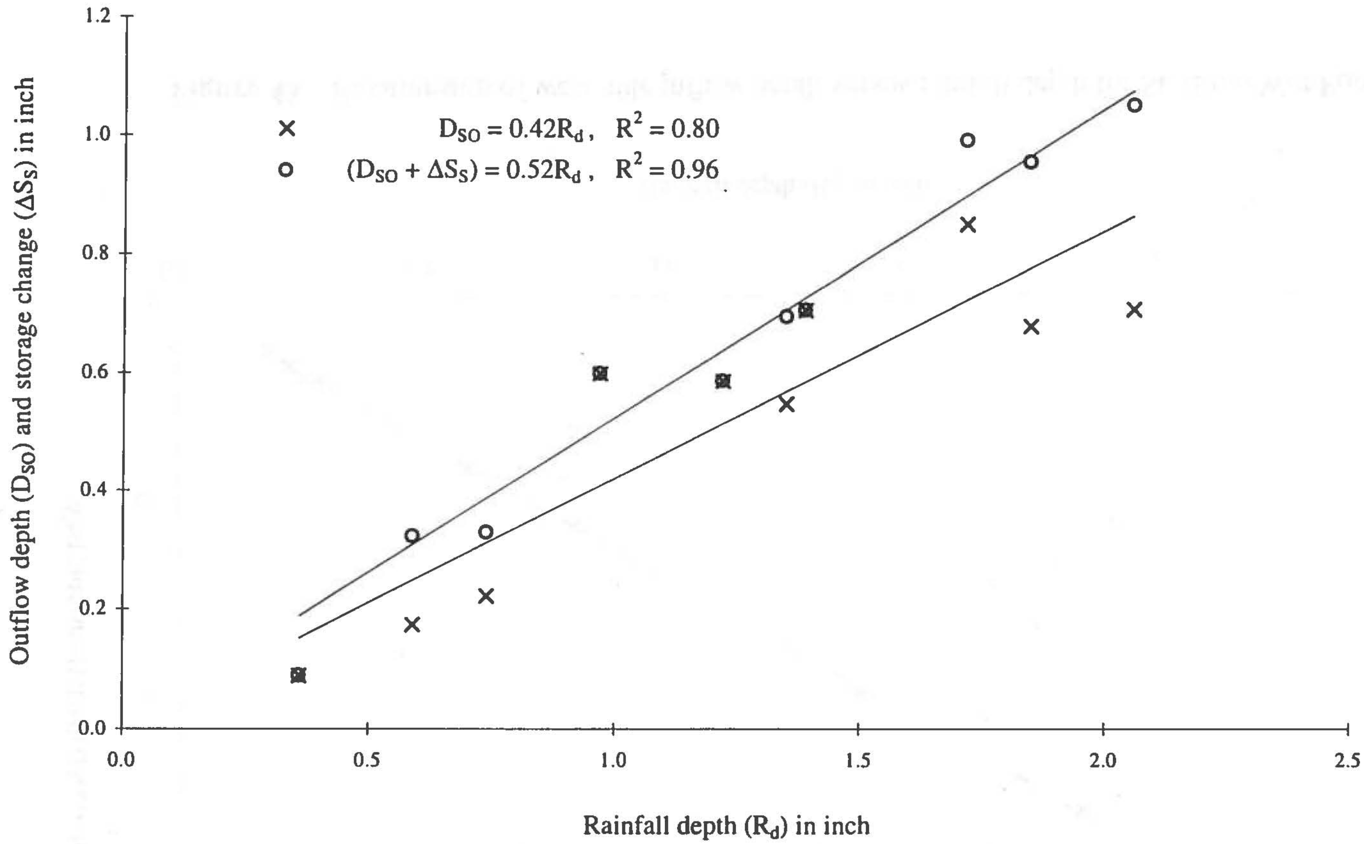


Figure 44. Relationship of outflow depth versus rainfall depth for St. Elmo Wet Pond

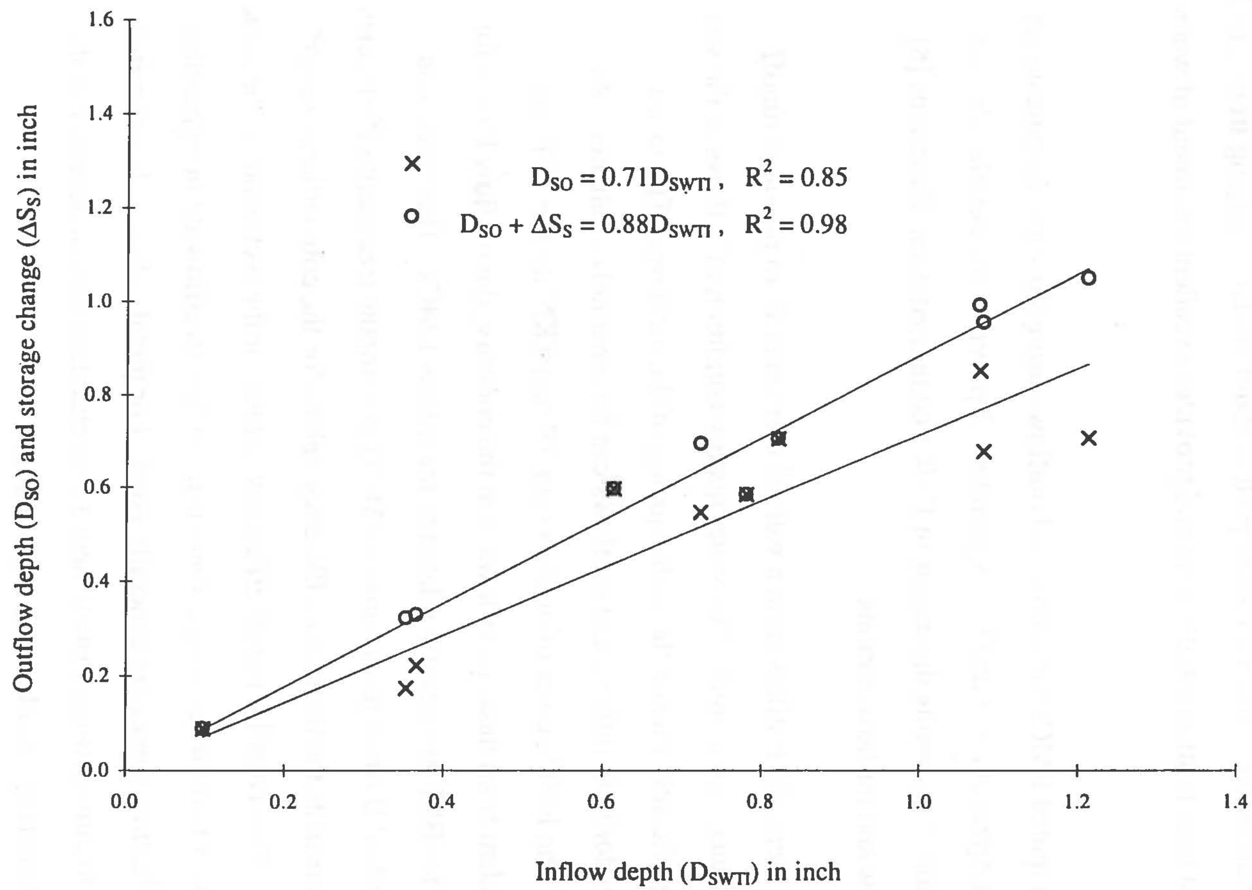


Figure 45. Relationship of outflow depth versus inflow depth for St. Elmo Wet Pond

of about 10-15 percent. The water loss may also have impacted the mass balance accounting. Generally, there is a potential problem of water loss through the bottom of the pond as identified by previous studies (COA, 1990a). The flow accounting for a 6-month period (April 1995 to September 1995) indicates that the average hydraulic resident time of runoff water in the permanent pool is about 30 days, ranging from 2 to 70 days. This resident time is substantially long and provides excellent treatment of water in the pond.

The grant study computed EMCs for inflow and outflows using flow and instantaneous concentration data (Appendixes B and E). Appendix C2 provides the detailed data of EMCs for SEP. Table 15 presents the means of EMCs computed using Equations [8] and [9] for all inflow and outflow stations.

For a single runoff event, the outflow from a wet pond is water from previous runoff events stored and treated in the pond. The water quality condition of inflows to the wet pond should not significantly impact the water quality of the outflows. The mean concentration values for both inflows and outflows can be separately evaluated. As shown in Figure 39, the EMC values of outflows for TP and TKN for the SEP are completely independent from those of inflows. On the contrary, the outflow EMCs for TSS, TKN, and TP for BRP are linearly related to the inflow EMCs. Therefore, this grant study used method B (used the means of EMCs) to compute treatment efficiencies for SEP. Table 16 presents the treatment efficiency values for the conventional runoff parameters for SEP. The overall removal efficiency values for the wet pond is the same as those of the treatment efficiencies since there is no inflow overflowing or bypassing the pond. These efficiency values are generally good. For metals, this study estimated the effectiveness of treatment using instantaneous concentration data of several runoff events. Table 17 presents the results of the estimation.

The study further computed the flow volume-weighted averages of instantaneous concentrations for all SEP monitoring stations. Table 18 shows the overall flow volume-weighted means calculated from a series of instantaneous concentration values and their

Table 15

Averages of Event Mean Concentrations (EMCs) for Monitoring Stations at St. Elmo Wet Pond

Pollutant Parameters	No. of Storms	SWI East-Side Inflow	SWJ West-Side Inflow	SWIJ Other** Inflow	SWE Wet Pond Outflow
TSS*	3 - 10	141	41	69	9
BOD	2 - 8	6.5	4.0	4.9	2.4
COD	3 - 10	46	43	46	23
TKN	3 - 10	1.06	0.85	1.30	0.47
NO_2+NO_3	3 - 7	0.75	1.01	0.74	0.45
NH_3	3 - 10	0.30	0.19	0.19	0.03
TN	3 - 10	1.81	1.85	2.04	0.92
TP	3 - 10	0.31	0.19	0.24	0.04
DP	2 - 9	0.08	0.11	0.11	0.03
Fe. Col.	2 - 5	99,341	13,556	12,074	1,324
Fe. Strp	2 - 5	38,887	44,755	14,105	1,265

* Averages of EMCs are sample means of log-normally distributed EMC data as explained in the text. The unit of concentrations for bacteria is colonies per 100 milliliters. The unit of concentrations for other parameters is milligrams per liter.

** "Other Inflow" is runoff from the intervening area. There is no measured EMCs for this area. Values in the table were estimated from concentration values of rainfall and "Lost Creek" stormwater monitoring site (COA, 1996a). Concentration values for west-side inflow are mostly impacted by the mixing of ponding water with the inflow.

Table 16

Removal Efficiency of St. Elmo Wet Pond Based on a Comparison of EMC Averages Between Inflows and Outflows

	SWTI Inflow	SWE Outflow	
Site Name	St. Elmo Wet Pond		
Land-Use Type	Industrial		
Drainage Area	27.11 acres		
Impervious Cover	66%		
No. of Concentration Values	*	*	**Annual *** Removal Efficiency (%)**
Event Mean Concentrations	EMC_i	EMC_o	
Pollutant Parameters **			
TSS	128	9	93
VSS	15	3	80
BOD	6	2.4	61
COD	46	23	50
TOC	9.0	5.7	36
$NO_2 + NO_3$	0.75	0.45	40
TKN	1.10	0.47	57
NH_3	0.28	0.03	91
TN	1.85	0.92	50
TP	0.30	0.04	87
DP	0.09	0.03	66
Fe. Col.	83,633	1,324	98
Fe. Strep.	34,426	1,265	96

* Number of EMC values varies depending on stations and pollutant parameters (see Table 15).

** The unit of all parameters other than Fe. Col. and Fe. Strep. is milligrams per liter. The unit of F. Col. and F. Strep. is colonies per 100 milliliters.

*** The annual removal efficiency of St. Elmo pond is same as the treatment efficiency of the pond since no runoffs overflow and bypass the pond.

Table 17

Removal Efficiency of St. Elmo Wet Pond Based on a Comparison of Averages of Median Instantaneous Concentrations Between Inflows and Outflows

Pollutant Parameters	No. of Events	East-Side Inflow	West-Side Inflow	Other* Inflow	Total Inflow	Wet Pond Outflow	Removal Effeciency
Cd	19	1.02	0.86	0.10	0.80	0.79	1.6
Cu	18	10.59	16.84	9.00	10.00	4.22	57.8
Pb	19	7.87	7.85	3.00	6.45	3.91	39.4
Zn	19	101.41	91.45	26.00	81.07	59.59	26.5

* Concentration values for inflows and outflows except 'other inflows' are arithmetic means of median event concentrations (medians of instantaneous concentrations for individual runoff events). Values for "other inflows" were estimated from concentration values of rainfall and "Lost Creek" stormwater monitoring site. The unit of concentration values is microgram per liter.

Table 18

Values of Flow Volume - Weighted Means of Instantaneous Concentrations for St. Elmo Wet Pond

Pollutant Parameter	SWI Concentrations of Inflows from the East-Side			SWJ Concentrations of Inflows from the West-Side			SWE Concentrations of Outflows from the Wet Pond		
	Number of Observations	Mean	Median	Number of Observations	Mean	Median	Number of Observations	Mean	Median
TSS*	43	141*	96*	34	164*	28*	87	11*	4*
VSS	43	14.6	11.0	34	20.9	4.0	87	3.11	2.00
BOD	38	5.7	5.5	31	7.4	5.0	71	2.8	2.0
COD	44	44	39	34	45	37	87	25	22
TKN	44	1.110	0.885	34	0.824	0.670	87	0.572	0.400
NO23	42	0.701	0.670	34	1.120	0.490	87	0.931	0.120
NH3	43	0.209	0.160	34	0.271	0.280	87	0.038	0.020
TN	42	1.78	1.53	34	1.94	1.32	87	1.50	0.66
TP	43	0.274	0.250	34	0.207	0.125	87	0.052	0.020
DP	44	0.080	0.070	26	0.124	0.060	75	0.029	0.020
TOC	42	9.02	7.76	34	8.62	6.43	87	5.52	4.92
CU	.	.	.	.	.	.	.	.	.
CD	.	.	.	.	.	.	.	.	.
PB	.	.	.	.	.	.	.	.	.
ZN	.	.	.	.	.	.	.	.	.
FE. COL.	23	49700	24400	26	40700	2400	41	3540	400
FE.. STRP	25	32900	37500	26	24600	18800	41	3090	400

* The unit of bacteria is colonies per 100 milliliters. The unit of other parameters are milligrams per liter.

corresponding flow volumes. For most parameters, these mean values are comparable with the sample means of EMCs of Table 15.

The water quality of rainfall may have some impacts on the water quality of outflows from SEP. The rainfall concentration values of nitrogen parameters such as NH3, NO2+NO3, and TKN for the Austin urban area can be very high. There are some high NO2+NO3 concentration values, mostly in the range of 1 to 3 mg/l. Table 19 presents the average concentration values of rain water for the urban area for most of the conventional runoff parameters. It is noticed that the concentrations of rain water for the urban area is significantly higher than those for the undeveloped site.

The rain water falling on the pond surface is considered as part of the inflow to the wet pond. The impact of rainfall quality on the removal efficiency of St. Elmo pond was quantified. The concentration values of inflows to the pond is computed as the averages of concentrations of the monitored and ungaged inflows weighted by the drainage areas. The concentrations of the "east-side inflows" represent those of the monitored areas. The concentrations of the rain water and the Lost Creek monitoring site represent those of the ungaged areas (see Table 15).

The impact of draw-down time of outflows on treatment efficiency can be significant. For larger runoff events (greater than 1.8-inch rainfall) the runoff may replace the entire volume of the wet pond's permanent pool. A portion of the runoff will exit the pond without a residence period. This portion of runoff was treated through the draw-down process of outflow. Figure 46 presents the relationship of draw-down time versus inflow. According to the equation in Figure 46, the draw-down time for an inflow of 1-inch (or a rainfall depth of 1.70-inch), is about 52 hours. This time is sufficient for some particulate matter to settle in the pond.

The design of St. Elmo Wet Pond follows the COA and nationwide guidelines. Through storm water monitoring and assessment, it was found that the performance of this pond complies well with the specifications of the design. The data from monitoring indicates that the pond is effective in controlling NPS pollution. Nevertheless, the maintenance of

Table 19

Rainfall Concentration Values for Austin Area*

Pollutants Parameters	Median (mg/l)	Arithmetic Mean (mg/l)
TSS**	0	0
VSS**	0	0
BOD**	2.5	3.8
COD**	19	22
NO_2+NO_3	0.44	0.70
TKN	0.66	0.88
NH3	0.26	0.48
TP	0.07	0.08
DP	0.06	0.06

* Values in the table should not be applied to undeveloped, rural site.

** Data of these parameters were obtained from the Water Resource Institute of the University of Texas at Austin. Samples of other parameters were collected at St. Elmo Wet Pond monitoring site.

Storm ID	Size of Total Inflow Q_{SI} (Inch)	Pond Drawdown Time T_D (Hour)
950405A	0.43	30.4
950508A	1.32	62.4
950611A	0.68	38.7
950907A	1.48	67.0
950920A	0.37	28.8

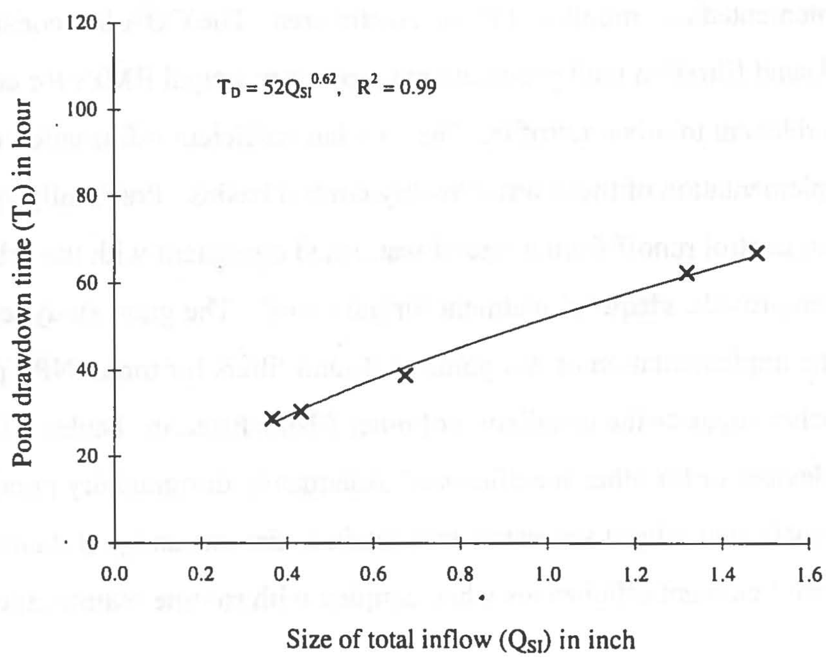


Figure 46. Pond drawdown time versus size of total inflow for St. Elmo Wet Pond

the pond and the adjacent areas is also an important factor in determining the long-term adequacy of its performance. The drainage pipe of outflow from the pond is fairly long. Substantial sediment often accumulated in the pipe requiring timely maintenance. On the other hand, adequate control of weeds and plants is necessary. The COA has made significant efforts in landscaping for this wet pond project. Vegetation for uptake of dissolved pollutants is abundant but it does need periodic maintenance. In addition, public perception of the wet ponds as an aesthetic amenity must be supported with an education program which explains periodic algae blooms and macrophyte dominance as normal transient conditions for this type of control.

4.3 Summary of Design Criteria for Various BMPs

Tables 20 and 21 provide design criteria and treatment efficiencies for various BMPs that have been implemented and monitored in the Austin area. The COA has considered that wet ponds and sand filtration with pre-treatment are two principal BMPs for controlling NPS pollution relevant to urban retrofits. The City has sufficient information on the design and implementation of these water quality control basins. Practically speaking, these basins can control runoff from a size of watershed consistent with the urban retrofit program and can provide adequate treatment for the runoff. The grant study team recommends the implementation of wet ponds and sand filters for major NPS pollution controls. It further suggests the installation of other BMPs listed in Tables 20 and 21 as pre-treatment devices or for other specific uses. Adequately designed dry ponds, vegetative channels, and oil/grit separators can detain sediments and pollutants, and provide moderate treatment efficiencies when coupled with routine maintenance.

4.4 Cost/Benefit Analysis

Other factors in addition to the removal efficiency need to be considered when evaluating the appropriateness of implementing BMPs. Other factors to consider are the initial construction costs, maintenance costs and the cost-effectiveness of the controls. The City has recently adapted the "Methodology for Analysis of Detention Basins for Control of Urban Runoff Quality" (EPA, 1986), a spreadsheet model, as one method for estimating

Table 20

Design Criteria for Various Quality Control Ponds and other BMP's

Type of Ponds or BMP's	Filtration Area (Acres)	Avg. Drawdown Time* (Hours)	Water Quality Volume (Inch Per Acre)	Other Major Consideration
Dry Pond	n/a	12-24	≥ 1/2	Baffle & Long Flow Path
Sand Filtration	.002~.011 (A)**	24	≥ 1/2	Pre-treatment & Dimension of Sand Bed
Wet/Dual Purpose Pond	n/a	< 36	0.50-1.10***	Landscape, Vegetation, and Sediment Forebay
Grassed Channel	Wide Cross Section Area	Long/Mild Slope	Vary****	Vegetation Density
Oil/Grit Separator***	n/a	4	Vary****	Baffle & Long Flow Path

* Drawdown time is the total time required for the outflow to leave the structure (to pass at least 80% of the outflow).

** A is the contributing drainage area above the structure. Filtration area is .002A to .005A depending on the type of Pre-treatment.

*** Wet ponds are designed to have a WQV sufficient to provide a 14-day hydraulic residence time. Volume will vary with site impervious cover.

**** Some runoff may not be treated. Runoff water may infiltrate (for grassed channel) or overflow (for oil/grit separater). An oil-grit separator for storm water treatment should have sufficient storage capacity in order to be effective.

Table 21

Treatment Efficiency* for Various BMPs

	Wet Pond** (Modified)	Wet Pond (New Design)	Sand Filter (W/Splitter)	Sand Filter (W/Pretreat)	Dry Pond (Concrete)	Dry Pond (Earth/Grass)	O/G Separator (Multi-Chamber)	Grassed Channel (Mild Slope)
TSS	46	93	87***	89	57	16	17	68
BOD	30	61	51	51	33	23	-19	33
COD	31	50	67	55	34	8	42	33
NO_2+NO_3	36	40	-82	-76	3	43	5	-2
TKN	14	57	62	50	33	12	40	32
NH_3	17	91	76	53	7	47	24	38
TN	29	50	31	17	28	22	4	23
TP	37	87	61	59	49	3	-	43
DP	-	66	-	3	23	-	-	34
Cu	41	58	60	72	6	19	-	-
Pb	72	39	80	86	34	16	-	-
Zn	64	60	80	76	48	-63	-	-

* Annual removal efficiency will be lower (up to 40%) for BMPs that have stormwater by-pass, overflow, or loss through infiltration.

** Modified wet pond -- Wood Hollow Detention Pond; newly designed wet pond -- St. Elmo Pond; sand filter with diversion splitter but no pre-treatment -- Jollyville Road Pond I; sand filter with splitter and pre-treatment -- Barton Ridge Plaza Pond; earth/grass dry pond -- Maple Run Sedimentation Pond; concrete dry pond -- Barton Ridge Plaza Sedimentation Pond - pre-treatment; O/G separator -- pre-treatment device for wet pond at the COA Convention Center; grassed channel -- grassed channel drains runoff from a residential area in the Travis Country Subdivision.

*** The main purpose of pre-treatment is to prevent sand bed from clogging, instead of improving treatment efficiency. There has been some drainage problems at Jollyville Road Pond I that has no pre-treatment device.

cost-effectiveness of potential control structures. Estimates of maintenance costs are used in the calculation of annual expenditures.

Model evaluations for St. Elmo Wet Pond and Barton Ridge Plaza are shown in Figures 47 and 48. Table 22 shows the average cost-effectiveness calculated based on the effectiveness as measured (method A and B) in this project. The cost effectiveness figures based on the two methodologies are very similar. Cost effectiveness for other structures was also estimated with the EPA Model or with measured removal efficiencies. This cost-effectiveness information along with an assessment of the comparative removal efficiencies and reliability factors is shown in a comparison matrix in Figure 49.

In examining the basis and variation in the cost-effectiveness factors, the dominant components identified were the drainage area to the pond and the capital cost of the project. The drainage area factor is directly related to the load treated by any on-line facility. In the case of the Woodhollow Detention Pond, even though the treatment efficiency is low, the overall total pounds removed remains high. Therefore, in general, when an area must be retrofitted with control structures rather than incorporating controls in the initial planning and design, regional facilities will be more cost-effective. The very low capital output for grassed swales or detention irrigation system also allows them to be very cost-effective facilities where appropriate (Santos and Associates, 1995).

Another important factor is the degree to which a facility treats different constituents. A system which primarily captures solids without treatment of dissolved constituents may only be applicable where the receiving water body problems are not related to eutrophication or algae blooms. Finally, maintenance is an important factor, but is difficult to assess. Different controls require different types of maintenance. Filter systems require more frequent maintenance or clogging will immediately impact performance. Barton Ridge Plaza is an example where the sedimentation basin provides for easier and less expensive removal of sediments and thus encourages regular maintenance before failure. Wet facilities, depending on design can achieve good performance over a long period of time, unless sediment build-up significantly reduces

Figure 47. Barton Ridge Plaza Model Analysis			
SITE NAME	**Barton Ridge**		
Evaluating EXISTING or FULLY-DEVELOPED Condition?	**F-D**		
SITE CHARACTERISTICS			
Drainage Area DA (acres)	**2.96**		
Site Imperviousness IC (%)	**81**	**Enter as PERCENT not FRACTION**	
Is Site in Recharge Zone?	**N**	Y or N	
Site Runoff Coefficient Rv	0.77		
MEAN ANNUAL STORM STATISTICS	Mean	Coefficient of Variation	
Duration (hr)	7.82	1.01	
Intensity (in/hr)	0.106	1.18	
Volume (in.)	0.60	1.32	
Delta (hr)	172.1	1.27	
Annual number of events	51.8	0.18	
Annual Precipitation (in.)	31.08	0.28	
MEAN ANNUAL STORM RUNOFF STATISTICS			
Mean Runoff Rate QR (cfh)	874		
Mean Runoff Volume VR (cu.ft.)	4,947		
BMP CHARACTERISTICS	Inches	Cu. Ft.	Ac-Ft.
Water Quality Volume VB (in.)	**0.65**	6,961	0.16
Filtration Surface Area SA (sq.ft.)	**280**	Typ. "Partial" SSF SA = Ad*H/10; "Full" SSF SA = Ad*H/18	
Filtration Media Hydraulic Conductivity (ft/day)	**3.50**	Typ. "Partial" SSF = 2; "Full" SSF = 3.5 (MAY BE CONSERVATIVE)	
Filtration Media Hydraulic Conductivity (ft/hr)	0.15		
Design Basin Depth (above filtration media ft.)	**3.00**	Generally 6' or less	
Depth of Filtration Media (ft)	**1.50**	Generally varies between 1 -1 .5'	
Assumed Design Hydraulic Gradient (ft/ft)	2.00		
Approx. Design Storm Treatment Rate (cfh)	114		
Approx. Design Drawdown Time (hrs)	**61.2**	**IS THIS REASONABLE? Criteria is 40 hours.**	
RUNOFF VOLUME CAPTURED DUE TO FLOW-CAPTURE			
Maximum Hydraulic Gradient (ft/ft)	3.00		
Maximum Filtration Rate (cfh) QT	171		
QT/QR Ratio	0.20		
Annual Flow-Capture Volume	15%		
RUNOFF VOLUME CAPTURED DUE TO VOLUME-CAPTURE			
MAS Emptying Rate ER (cfh)	114		
MAS Empyting Rate Ratio E	3.96		
VB/VR Ratio	1.41		
Effective Volume Ratio VE/VR (Fig. 4)	1.30		
Annual Volume-Capture Volume (Fig. 3)	58%		
RUNOFF VOLUME CAPTURED DUE TO COMBINED FLOW-CAPTURE AND VOLUME-CAPTURE			
Fraction Captured - Flow Capture	15%		
Fraction Captured - Volume Capture	58%		
Fraction NOT Captured - Flow-Capture Fq	85%		
Fraction NOT Captured - Volume-Capture Fv	42%		
Annual Capture Volume ACV	64%		
TSS REMOVAL			
TSS EMC (mg/L)	**282**		
Annual Load In (lbs/yr)	4,191	2.10	tons/yr
Annual Capture Volume	64%		
Average Event Removal Efficiency	**89%**		
Annual Percent Load Reduction	57%		
Annual Load Removed (lbs/yr)	2,378	1.19	tons/yr
TSS COST-EFFECTIVENESS	Planning Estimate	CIP Estimate	Actual
Capital Cost	$ 13,985	$ 1	$ 279,000
Annual O&M Cost	$ 439	$ 1	$ 2,000
Life of BMP (years)	25	25	25
Annualized Cost	$ 999	$ 1	$ 13,000
Cost-effectiveness ($/lb TSS removed)	$ 0.42	$ 0.00	$ 5.47

Figure 48. St Elmo Wet Pond Model Analysis					
SITE NAME	**st elmo**				
Evaluating EXISTING or FULLY-DEVELOPED Condition?	**F-D**				
SITE CHARACTERISTICS					
Drainage Area (acres) DA	**27.11**				
Site Imperviousness (%) IC	**66**	**Enter as PERCENT not FRACTION**			
Is Site in Recharge Zone?	**N**	**Y or N**			
Site Runoff Coefficient Rv	**0.60**	Calculated from 1996 COA Data			
MEAN ANNUAL STORM STATISTICS	Mean	Coefficient of Variation			
Duration (hr)	7.82	1.01			
Intensity (in/hr)	0.106	1.18			
Volume (in.)	0.60	1.32			
Delta (hr)	172.1	1.27			
Annual number of events	51.8	0.18			
Annual Precipitation (in.)	31.08	0.28			
MEAN ANNUAL STORM RUNOFF STATISTICS					
Mean Runoff Rate QR (cfh)	6,259				
Mean Runoff Volume VR (cu.ft.)	35,427				
BMP CHARACTERISTICS	Inches	Cu.Ft.	Ac-Ft.		
Permanent Pool Volume (inches)	**1.76**	173,200	3.98	Use for Evaluating Effectiveness	
Sediment Storage Volume (% of PP Vol)	**5%**	8,660	0.20		
Total Permanent Pool Volume (inches)	1.85	181,860	4.17	Use for Pond Construction Purposes	
Permanent Pool Surface Area (sq.ft.)	**71,700**	1.65	acres		
Average Permanent Pool depth (ft)	2.42				
Ratio of Surface Area to Drainage Area	6.07%				
Hydraulic Residence Time for Mean Annual Storm (days)	**35.06**	Minimum of 14 days recommended			
Hydraulic Residence Time for "Critical Month" = MAY (days)	**22.14**	Minimum of 14 days recommended			
"DYNAMIC" REMOVAL CALCULATIONS					
Treatment Rate QT for MAS (cfh)	6,259				
Detention Time for MAS (hr)	5.66				
Calculated Overflow Rate OR (ft/hr)	0.09				
Adjusted Overflow Rate OR (ft/hr)	0.17	Per Urbonas and Stahre recommendation to double calculated OR			
Coefficient of Variation of Flow COVq	1.18				
Short-circuiting factor n (1=poor design, 3=good, 5=excellent, little short-circuiting)	3				
COMBINED TSS REMOVAL					
Particle Size	Average Settling Velocity (ft/hr)	Dynamic Treatment Efficiency	Quiescent Treatment Efficiency	Approximate Combined Treatment Efficiency by Particle Size	
1	0.03	10%	86%	87%	
2	0.33	59%	86%	94%	
3	1.5	96%	86%	99%	
4	7	100%	86%	100%	
5	65	100%	86%	100%	
		73%	**86%**	**96%**	
ANNUAL AVERAGE TSS LOAD REDUCTIONS					
Inflow TSS Concentration (mg/L)	**120**	*from 319 Report, Dr. Chang			
Annual Watershed Load (lb/yr)	14,663				
Annual Load Removal Efficiency	**96%**				
Annual Load Removed (lb/yr)	14,109				
Annual Load Discharged (lb/yr)	554				
Annual Average Outflow TSS concentration (mg/L)	5				
TSS COST-EFFECTIVENESS	Planning Estimated	CIP Estimate	Actual		
Capital Cost	**$ 277,130**	**$ 300,000**	**$ 300,000**		
Annual O&M Cost	**$ 5,699**	**$ 2,400**	**$ 500**		
Life of BMP (years)	**25**	**25**	**25**		
Annualized Cost	**$ 16,784**	**$ 14,400**	**$ 12,500**		
Cost-effectiveness ($/lb TSS removed)	**$ 1.19**	**$ 1.02**	**$ 0.89**		

Table 22. Cost effectiveness of project control structures based on TSS removal.

	St. Elmo Wet Pond	Barton Ridge Plaza SF Pond
Annual TSS Load (lbs/year)	14,663	4,191
Removal Efficiency	93%	71%
Load Removed (lbs/year)	13,639	2,976
Capital Cost	$ 300,000	$ 275,000
Estimated annual costs	$ 500	$ 2,000
Cost Effectiveness ($/lb/year)	$ 0.92	$ 4.37
Cost Effectiveness as calculated with EPA Model	$ 0.89	$ 5.47

the capture volume. In this case, maintenance is a long-term expensive effort which needs to be planned for.

The overall assessment in Figure 49 indicates that large regional wet facilities are most cost-effective and treat a wide range of constituents. For smaller sites, a sedimentation/filtration system may be most appropriate with regular maintenance required. As described in previous sections, other types of facilities may be applicable for pre-treatment or for particular instances where low capital cost is essential or where lack of space requires an underground system such as an oil/grit separator. A final consideration, which the City is beginning to examine, is the benefit in terms of downstream erosion control which will be gained from the different devices. Often, increased channel flows and sediment produced by subsequent channel erosion are the dominant source of loads in developed areas.

Figure 49. Comparison Matrix

BMP	Removal Efficiency: TSS	Removal Efficiency: Dissolved nutrients*	Removal Efficiency: Metals	Cost Effectiveness	Reliability
St. Elmo Wet Pond	●	◐	◐	●	●
Barton Ridge Plaza	●	○	◐	◐	●
Jollyville Road Pond I	●	○	-	○	◐
Woodhollow Detention Pond	◐	○	◐	●	◐
Maple Run Sedimentation Pond	◐	○	○	-	◐
Barton Ridge Plaza/ sedimentation only	○	○	○	◐	●
Convention Center oil/grit separator	○	○	-	○	○
Travis Country grassed channel	◐	○	-	●	◐

* Dissolved nutrients, average of removal efficiencies for DP, NH3, NO2+NO3

KEY	Removal Efficiency	Cost-effectiveness	Reliability
●	> 80% removal	< $1/lb/year TSS	Good, consistent
◐	> 40% removal	< $10/lb/year TSS	Inconsistent performance
○	< 40% removal	>$10/lb/year TSS	Significant problems identified

5 DEVELOPMENT OF NON-STRUCTURAL BMP PROGRAMS

In addition to the structural controls testing, this grant also funded the development and evaluation of several nonstructural controls. The nonstructural control projects described herein were generated from this grant or implemented partially with grant funds. Continuing from this grant work, the City has made many additional efforts to provide public education about the fundamental principles of NPS pollution and the impact of citizen choices on waterways' health and uses. The major programs receiving full or partial funding through this project include various outreach programs, citizen monitoring, Waller Creek studies and Austin Youth River Watch. A citizen phone survey was used as an assessment tool to evaluate the effectiveness of these programs.

5.1 Outreach Programs

From surveys conducted by city staff it appears that many Austinites are unaware that NPS pollution increases with urbanization. The citizens are not aware that home, garden, and auto chemicals improperly used and disposed of are a major cause of NPS pollution. In addition, many do not realize that use of chemicals in landscape areas will eventually end up in the creeks, the lake and groundwater. The programs listed below were intended to raise NPS pollution awareness of the 300,000 residents that live within the urban watershed areas that drain into Town Lake.

5.1.1 "Give The Lake a Break" Poster

This poster depicted litter, automotive, and household toxics being discarded through a stormwater inlet and showed the resulting forms of lake degradation pictorially. Information on the back of the poster included:

- a definition of NPS pollution;
- an explanation of the relationship between storm drains and the lake;
- environmentally friendly tips for landscaping and auto care;
- the difference between storm sewers and sanitary sewers;
- nontoxic cleaning materials; and

- telephone numbers for further information, reporting spills or polluters, volunteering for clean-up programs, and for the City's Household Hazardous Waste Collection Facility.

5.1.2 "Now Showing at a Creek Near You" Poster

In a style similar to a movie poster, this poster depicted erosion, lawn chemicals, and litter polluting the creek. Similar to the "Give The Lake a Break" poster, information on the back of this poster included information on erosion, lawn maintenance, disposal of household products, litter, the City's Household Hazardous Waste Collection Facility, composting, and important telephone numbers.

5.1.3 Town Lake Turtle Costume and Television Public Service Announcements

This costume was designed and produced to become a water quality mascot for the City of Austin. It was used to promote water quality educational materials at schools and public performances, school programs, and media events. Two television public service announcements starring the Town Lake Turtle were produced and shown on local television stations. These announcements highlighted the hazards of landscaping chemicals and automotive waste disposal, storm sewer paths and functions, and their relation to NPS pollution.

5.1.4 "Cut the Crud" Campaign

The City of Austin recognized the need to increase awareness and educate business operators regarding non-point source pollution. The "Cut the Crud" campaign was developed to educate the owners, managers and supervisors of small businesses on the impact of nonpoint source pollution to Austin's creeks and lakes, and to motivate the group to take appropriate actions to prevent pollution at the workplace. The City determined that a "traditional" educational video would not reach the target audiences, so a script was created using the "Sam Spade" genre with the characters Storm Derrane, Emm Maculate, and Earl Slick as the hero, heroine, and the villian respectively. The City also organized three seminars for the targeted business audiences. Invitations were mailed to those businesses who had previous conditions that were in violation of the City Water Quality Ordinance, businesses who were located either through trade associations, or random selection from the yellow pages.

5.1.5 Program Effectiveness

Although it is difficult to quantify the effectiveness of outreach on water quality data, the responses to the programs were significant. Free posters were distributed at public functions through the City's Community Education division. During the first month after the news series and public service announcement (PSA) aired, over 900 calls were received on the voice-mail system, and over 1000 posters were mailed. During the next year, over 100 calls were received and posters sent out each month. The City also received group requests from companies including Motorola, IBM, 3M, AMD, AISD, Girl and Boy Scouts, and many other civic organizations. In May 1992, the City sent out 270,000 utility bill pamphlets containing a condensed version of the poster information. In addition, 120,000 half-sized posters were sent out with an issue of the local newspaper. The City has distributed over 50 "Cut the Crud" video tapes upon public request, including requests from other environmental agency staff. Over 200 interns and volunteer monitors collected samples and documented their water quality monitoring data. Eight reports from different monitoring groups were generated

Section 7 includes specific additional information on distribution and participation measures and survey results for evaluating the effectiveness of each of these programs.

5.2 Citizen Monitoring Program

Austin's citizen monitoring program, The Water Watchdogs, is a partnership formed between science instructors and students at area colleges (principally Austin Community College (ACC), and the City's Environmental Resource Management (ERM) Division. This partnership reaches a wide spectrum of the Austin population, teaching participants background on the causes and prevention of nonpoint source pollution, water quality assessment methods, and the watershed concept. Besides providing educational benefits, the program is designed to gather water chemistry data for rating and comparing water quality in streams and lakes of Austin. This information can then be incorporated in the planning and prioritization regarding the expenditure of funds to improve water quality through the implementation of BMPs. In some instances, the detection of hot spots in need of immediate attention can lead to direct action towards improving water quality. Overall, the program educates and heightens the environmental awareness of its volunteers by dealing with nonpoint source pollution issues, establishes trust between citizens and regulatory officials, and encourages citizens to protect and restore Austin's streams and lakes.

For the Water Watchdogs, citizen-volunteers were organized to monitor the water quality of Town Lake and it's tributaries. Parameters were selected to monitor for pollution problems documented on Town Lake, including:

- Sediment loading and response: TSS, turbidity
- Nutrient loading and response: NO3, NH3, PO4, DO, temperature
- Leaking sanitary sewers or other bacteria sources: Fecal coliform
- Salinity: TDS
- Spills and toxics: BOD, pH, immunoassay toxicity testing, odor, discoloration, and bioassessment (benthic macroinvertebrates and algae cover).

Enhancements to this program were included as part of this grant as part of the source controls programs which may provide pollutions controls through educational efforts. As such, the data obtained through this program was not used in evaluating the effectiveness of either treatment or source controls. Therefore, the QA for this program was not included in the Quality Assurance Project Plan, but rather complies with the QA/QC for the overall Water Watchdogs program for the City.

Results from Water Watchdog data (COA, 1992) showed that less developed creeks and Town Lake headwaters have substantially better water quality than fully developed, urbanized creeks and lower reaches of Town Lake. Two reports were made on QA/QC protocols and results for the Water Watchdogs program.

- First report is "Quality Assurance and Quality Control on Citizen Monitoring Team Results with Comparisons of Data Obtained from Testing Kits, Specialized Meters, and Laboratory Testing, Eric Brown and James Buratti, City of Austin, 1992." This study assessed the QA/QC of citizen water quality monitoring test results, and recommendations were made to improve quality for each parameter.

- Second report is "QA/QC on Fecal Coliform and Turbidity Tests Performed on Barton Springs Water and A Study of the Effects of Rainfall on Fecal Coliform Counts and Turbidity Readings, Eric Brown and James Buratti, City of Austin, 1992."

  This report analyzed a comparison of water quality data from the Austin/Travis County Health Department to that of a City QA/QC team.

A region specific index, integrating all water chemistry parameters from this program, was used to rate the impact of nonpoint source pollution at each monitoring site. This 319 Grant specifically targeted the Water Watchdogs program for Waller Creek.

Along with most other fully developed, urbanized creeks, Waller Creek's water quality is shown to be substantially lower than the relatively undeveloped Barton Creek. Town Lake, it's receiving water body, is shown to be degraded compared to the relatively undeveloped waters coming from Lake Austin.

5.3 Waller Creek Studies

Additional educational and informational programs and studies were initiated through several study grants awarded in the summer of 1991 to leaders within Austin's Citizen Monitoring Program. These grants involved college students and citizens from the Austin area in a comprehensive assessment of Waller Creek to provide the City with a baseline of information that might be useful to planners making future watershed management decisions. A brief summary of these follows.

5.3.1 A Survey of the Aquatic Macrobenthos of Waller Creek

The report entitled "A Survey of the Aquatic Macrobenthos of Waller Creek, Stephan W. Ziser, PhD, Austin Community College, Assisted by Patricia Maxwell, Audrey Pierce, Steve Garza, Cindy Goodwin and Glen Jacobson, 1992" provides details concerning an investigation of the benthic macroinvertebrate fauna along Waller Creek. Conclusions resulting from the investigation include:

- Waller Creek benthic populations are principally composed of five rapidly growing taxa able to take advantage of ephemeral aquatic habitats.
- Predatory taxa are less common than collector/gatherers and trophic generalists.
- Species with restrictive microhabitat requirements are rare.
- Fauna in Waller Creek are similar to other ephemeral creeks such as Blunn and East Bouldin Creeks.

5.3.2 The Algae of Waller Creek

The report entitled "The Algae of Waller Creek, Jerry Coleman, PhD, Tim Wright, and Kenny Totz, St. Edward's University, 1992" provides details concerning algal community. The report identifies important members of the algal community indicator species, and specific influences that might affect the algal community. Conclusions resulting from the study include:

- Greater algal growth downstream suggests that the urban area is acting to enrich algal growth through nutrient inputs.
- Cladophora sp. dominate Waller Creek, while Spirogyra sp. is more common in cleaner waters
- Nuisance level algal growth was not observed during the course of this study.

5.3.3 The Flora of Waller Creek

The report entitled "Flora of Waller Creek, Robert J. George, Austin Community College, 1992: compiled a survey and photo journal of macrophyte plant species for Waller Creek. The report describes plant distribution in the watershed and identifies species with biorevetment, bank and streambed stabilization potential.

5.3.4 Waller Creek Geology

The report entitled "Waller Creek Austin, Texas, Geologic Past and Present, Patricia Bobeck, geologist, Austin Community College, 1992" describes geologic formations underlying the Waller Creek basin. The study analyzes urbanization impacts on channel morphology, floods, and nonpoint source pollution. Recommendations are also given for areas, based on soils, appropriate for the placement of structural BMPs.

5.3.5 Life on Waller Creek.

A video presentation entitled "Life on Waller Creek, a video photoessay, by Pam Brownlee and Yvonne Estes, PhD, Austin Community College, 1992" documents the beauty, land use, and water quality impacts on Waller Creek. The video documented how water contamination emanates from an array of sources rather than from a single point.

5.4 Austin Youth River Watch

The effort of the Austin Youth River Watch program included monthly monitoring of St. Elmo pond by students from Mendez Middle School assisted by the grant staff. The staff met the students at the pond weekly for a 28 week period to instruct them in field monitoring practices, distribute information on pond design and function, and provide education on nonpoint source pollution. The Austin Youth River Watch program is part of the City's community education efforts administered through the Colorado River Watch Fondation.

5.5 Non-point Source Phone Survey

The behavioral patterns of all persons in the City may collectively determine the level of NPS pollution. Poor habits greatly exacerbate the problem while informed, conscientious habits can effectively minimize the threat. In response, a central focus of the City's water quality efforts has been to conduct a city-wide public education campaign promoting behavior consistent with environmental stewardship in general and NPS pollution control specifically. To increase the overall effectiveness of the public education programs including the citizen monitoring, the City conducted a statistical survey of public awareness and education about NPS pollution.

5.5.1 Survey Approach

The NPS survey was conducted by phone from December 1992 to March 1992 to determine the knowledge and behavioral patterns of citizens in Austin, Texas. Approximately 200 respondents were randomly interviewed using a hybrid random digit dialing method. Respondents were not pre-screened. However, questionnaires from persons determined to be too young were discarded.

The survey consisted of sixteen questions with the following themes:

- The means by which NPS pollution enters waterways (knowledge),
- Use of chemicals (behavior),
- The impact of various NPS inputs into the environment (knowledge),
- Disposal of oil and household hazardous wastes (behavior), and
- Demographic Questions (general information).

5.5.2 Results

<u>Summary of Data Analysis:</u> The data set derived from the phone survey produced useful information about a range of NPS topics. Demographic information was gathered on the gender, ethnic origin, age, and geographic region of each of the respondents. These categories, along with the overall results, were used to draw conclusions about the data. Chapter Five gives detailed analyses for each of the questions using all of the subgroups. A summary of the overall results is presented here.

<u>Lawn Care Questions:</u> Lawn care questions were asked only of persons who had lawns and/or gardens which were cared for by the respondent or another household member. Since not all persons surveyed met these conditions, the population of persons sampled was smaller than those for other more general questions. This limited the ability to analyze the results for many of the subcategories (gender, race, age, and geographical region).

General Use of Pesticides and Herbicides. Approximately half of those polled reported that they used pesticides and herbicides to care for their lawns and/or gardens. The question was constructed to encourage "yes" answers. Despite this attempt, the actual use levels are likely to be somewhat higher than those of the survey results. Even using the lower figure, these kinds of products appear to be prevalently used and exposed to the environment.

Of those respondents who used chemicals, almost 70% applied them only as needed as opposed to administering them on a regular basis. However, one-fifth of the respondents reported the latter behavior. The "as needed" approach is more desirable from both an NPS control and an effectiveness standpoint, accomplishing the same end with fewer dosages. These findings imply a need to educate a sizable portion of the population on appropriate chemical application practices.

Knowledge of Professional Lawn Care Chemical Applications. The majority of persons (80%) who used professional lawn care services were not aware of the chemical products that were being used by these services on their lawns.

These results unsurprisingly indicate that a portion of the population is not taking an active interest in lawn care chemical use. The usefulness of the results is limited due to several inherent problems. Additional effort would be necessary to adequately explore the professional lawn care issue with respect to NPS pollution.

Fertilizing Before Rainfall Events. Approximately the same number of respondents reported that they would (44%) and would not (48%) apply fertilizers before a heavy rain. The question was constructed such that a "yes" answer would appear acceptable. The results indicate a sizable percentage of the public may not be aware and/or concerned about fertilizer contamination of runoff.

Fire Ant Control. Most (64%) of respondents reported using some form of chemical control for fire ants. Within this group, most (63%) used either Logic or Amdro, two relatively benign treatment alternatives. The remainder used more toxic products or were unsure of the exact substance used. Most of the respondents (22%) used no treatment at all or applied boiling water to the ant hills. A small, but notable group (3%) used motor oil or diesel as a control. Figures for Amdro, Logic, and no treatment were probably inflated for a variety of reasons, such as the propensity to over-report names of both brands, and "socially desirable" behaviors. The results indicate that a public education campaign should target this specific pest control issue. The topic is well known and popular among citizens and represents a potentially major source of NPS pollution. The poison-free use of boiling water could be an important component of the education message.

Leaf and Grass Clipping Disposal. Two different questions were used in gauging how the public dealt with waste leaf and grass matter. Initially, respondents were asked if they composted these materials, which yielded responses judged to be unrealistically high (42%). The question was reworded to ask about disposal in general, producing more realistic data. Half of the respondents reported bagging their leaves/clippings, a quarter left them on the lawn, and the remainder composted clippings. The public education campaign could logically focus upon the large group which sends its organic wastes (a resource) to the landfill.

<u>**General NPS Knowledge and Behavior Questions:**</u> A set of general questions was asked of all respondents. These questions dealt with important subjects gauging the respondents' knowledge of and behavior affecting levels of NPS pollution. With the large data set obtained, more reliable results were generated for the various analytical subcategories (gender, race, age, and geographical region).

Destination of Storm Water Runoff: The survey asked whether respondents knew where storm water goes after entering storm sewers. The question addressed the important connection between runoff and pollution in waterways.

The data show that almost half (48%) of those surveyed were unsure of the final destination. 38% correctly answered that it went to creeks or waterways, and the remaining 15% incorrectly stated that it was somehow treated. The question was worded to encourage "Don't Know" responses rather than incur high numbers of guesses. These results indicate a widespread lack of knowledge about one of the most fundamental engines of NPS pollution. As such, the topic is an ideal subject of the public education campaign.

Relative Harm of Chemical vs. Natural Fertilizers: Few respondents (7%) selected cow manure as more environmentally harmful to waterways than chemical fertilizers. Notwithstanding attempts to carefully word the question, a skewed data set was obtained. Almost two-thirds correctly selected chemical fertilizers, with the balance answering "Don't Know" (27%). The fact that over a quarter were still unsure potentially makes it a suitable subject for the public education campaign. One important matter remains for the subject of another study: whether proper knowledge of the relative harm affects the publics' decision to choose natural over chemical fertilizers.

Environmental Consequences of Organic Matter in Creeks: Almost half of the respondents reported leaves and grass clippings to cause problems in waterways beyond those of clogging. Around 30% said that they were not a problem, with the balance (22%) not sure. The question was worded to balance the responses against the safer response of "yes" (that is a problem). While natural systems can cope with some inputs of these materials, urban roads and storm sewers send much larger quantities into receiving waters than occurs in undeveloped settings. With over half of survey respondents either unsure or incorrect on this point, the matter should be addressed in the public education campaign.

Motor Oil Disposal. Around two-thirds of respondents reported having their motor oil exclusively changed in professional shops, leaving a sizeable portion changing and disposing of their oil themselves. This latter group was probably lower than exists in reality, with the propensity to choose the easier answer of "Take to shop," perhaps perceived as more environmentally responsible. Half of all respondents said they would take used motor oil to a shop for disposal, while fully 15% said they would dump it in the trash and 4% answered they would pour it on the ground. The balance (27%) were unsure. The results indicate a need to educate the public about both the need to take used oil to a shop to be recycled and that the substance is very harmful if released improperly into the environment.

Household Hazardous Waste Disposal. Almost 40% of respondents reported that they would dispose in the trash any left-over household products such as paint thinner and pesticides. Other significant groups said they would take them to the City of Austin's Hazardous Waste Center (22%), "Don't know" (20%), or would "Use it all up" (18%). Two respondents (1%) said they would dump them on the ground. Despite attempts to word it carefully, the question was a difficult one for many respondents.

As the last of many NPS questions, it was by then obvious that an "environmentally responsible" answer was expected. The results indicate that many persons are probably unaware of the City's Hazardous Waste Center and that much confusion exists as to proper disposal of such materials. Given the potential for NPS pollution, the matter should be the subject of the public education campaign.

A high percentage of respondents demonstrated a lack of knowledge about the fundamental principles of NPS pollution, water quality problems associated with disposal of organic debris in waterways, and how to properly dispose of petroleum products. In addition, a high percentage of respondents use pesticides and fertilizers, with approximately 50% applying them inappropriately before heavy rains.

Public education campaigns in years following this survey have targeted specific areas of concern revealed by the results.

6 TECHNOLOGY TRANSFER

Ongoing technology transfer opportunities have been incorporated with educational efforts and with requests from information from other agencies and states. Some recent efforts include:

- A press conference was held with international exchange students from Russia and City Council members at St. Elmo Wet Pond which demonstrated Austin's efforts in nonpoint source pollution control. An informational packet was assembled for public outreach at St. Elmo Pond which includes species specific landscape design and installation details (Appendix H).

- Effectiveness data for Barton Ridge Plaza is being provided to Rutger University's Civil and Environmental Engineering Department for effectiveness and design feature information on sedimentation filtration basins to incorporate in a NJ Department of Transportation manual entitled "Appropriate Runoff Control Methods for the Four Physiographic Regions of New Jersey."

- The performance evaluation and cost benefit analyses will be incorporated and documented in the City of Austin's citywide master planning process.

- Design criteria for wet ponds have been developed by the City of Austin to provide to interested developers and engineers, and adopted on September 6, 1997 as part of the City Environmental Criteria Manual (Section 1.6.6). The design criteria are based in part on the design and monitoring of the St. Elmo Wet Pond and are included in Appendix I.

The primary technology transfer effort, specific to this grant, was the City's participation in a conference on "Watershed Management: Challenges and Innovations." Over 8000 invitations were distributed for this conference to, among others, state, local, and national agencies. The conference sponsored by the Barton Springs/Edwards Aquifer Conservation District, the Lower Colorado River Authority, the City of Austin Environmental Resources Management Division (through this grant), and Espey, Huston & Associates was held on July 24-26, 1996 in Austin, Texas and included City of Austin presentations on BMPs. In particular, one presentation by City staff focused on the effectiveness and design of wet ponds in this region of the United States. This presentation included an analysis of results from the St. Elmo pond monitoring funded by this grant. The field trip associated with the conference included a site visit to the St.

Elmo pond. The City also received one of the 1996 Conservation Awards from the Barton Springs/Edwards Aquifer Conservation District for it's participation in that conference.

Included in Appendix J is the conference agenda and a copy of the conference evaluation forms which were developed by City staff and distributed to evaluate the effectiveness of this technology transfer effort. The appendix also includes the completed evaluation forms. Figure 50 displays a summary of the results of the Conference Evaluation. Over 90% of the respondents characterized the quality of the conference as good or very good, and the BMP information as useful. One hundred percent stated that they would use the information in their work and 85% felt that they had learned something new about BMPs and their effectiveness. The individual evaluations included in the appendix list topics respondents would like to see included or expanded in the future as a response to the fifth question. The respondents also submitted some unsolicited comments which should assist with the conference format in the future. The City plans on obtaining further feedback in the future on the implementation of the technology information provided to conference participants.

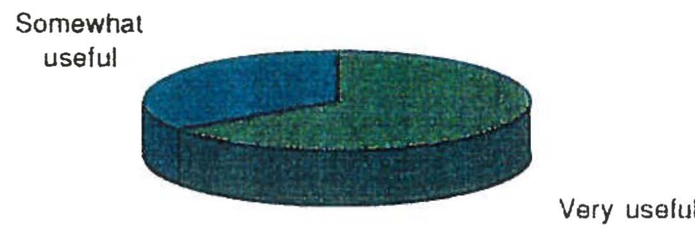
Figure 50

Conference Evaluation

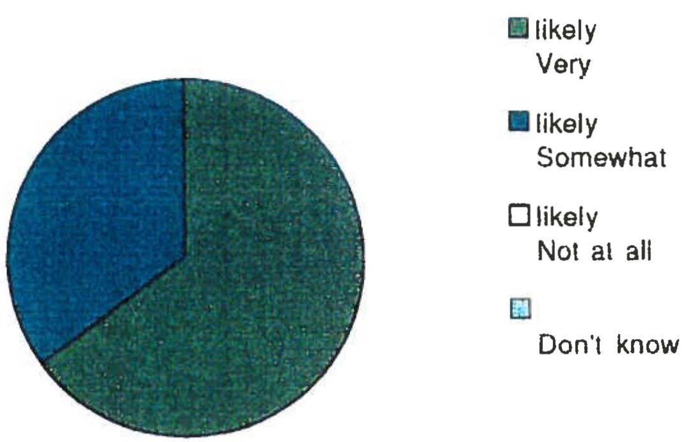
CITY OF AUSTIN
DRAINAGE AND UTILITY DEPARTMENT

1. QUALITY OF CONFERENCE

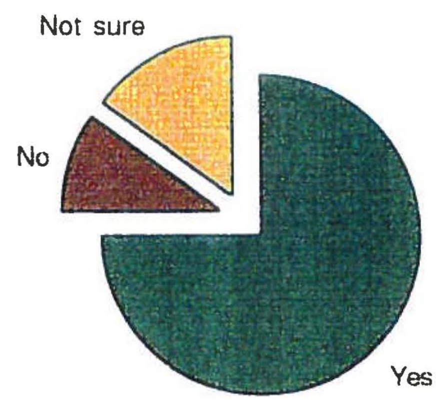
2. USEFULNESS OF BMP INFORMATION



3. INFORMATIONS USEFULNESS



4. DID YOU LEARN SOMETHING



7 CONCLUSIONS

The conclusions are divided into those derived from the two major components of the grant project, the evaluation of structural controls, and the implementation of nonstructural controls.

7.1 Conclusions of Evaluation for Structural BMPs

Project staff analyzed data collected from the monitoring projects for Barton Ridge Plaza Sedimentation/Filtration Ponds (BRP) and St. Elmo Wet Pond (SEP). The treatment efficiency values for various runoff pollutant parameters for both ponds are summarized in Table 23. The following conclusions were drawn from the results of this analysis in conjunction with previous COA BMP studies.

The BRP and SEP were implemented in accordance with the COA's design guidelines. The performances of these ponds generally comply with the desired functions of the original designs. This study recommends that wet pond and sand filtration basins of adequate design be used as primary structural BMPs for NPS pollution control.

The key elements for designing a sand filtration system are:

- a sand bed of fine sand (0.02" - 0.04" diameter) with sufficient thickness and bed surface area,
- a sedimentation pond or its alternative as a pre-treatment in order to warrant effective filtration,
- a splitter box to deliver at least 1/2-inch runoff to sand filtration system, and divert the remaining inflow to the downstream detention, and
- an easy access to the sand filtration system for maintenance.

The key elements for designing a wet pond are:

- a permanent pool that can provide sufficient "hydraulic residence time,"
- a water surface area (at the permanent pool level) of specific size and shape that can prevent short circuiting of flows,

Table 23

Computed Treatment Efficiencies for Barton Ridge Plaza Sand Filtration and St. Elmo Wet Ponds Using Measured Flow and Concentration Data (Efficiency in Percent)

Parameter	Barton Ridge Plaza * Sedimentation/Filtration System	St. Elmo Wet Pond
TSS	89	93
BOD	51	61
COD	55	50
NO_2+NO_3	-76	40
TKN	50	57
NH_3	53	91
TN	17	50
TP	59	87
DP	3	66
Cu	72	58
Pb	86	39
Zn	76	60

* The overall annual removal efficiency for the Barton Ridge Plaza pond system will be lower since a portion of the inflow by-passes or overflows the system without treatment. It is estimated that the annual removal efficiencies for the system will be about 20 percent lower than those listed in this table.

- a flow outlet device that provides sufficient draw-down time for the outflow to pass through,
- a landscape plan that provides vegetation uptake and beautifies the environment, and
- a sediment fore bay for sediment control and removal.

The maintenance of ponds is important. During the first year of operation, it is necessary to inspect the structure during and after significant runoff events in order to find the source of all problems. After the first year, it is necessary to inspect and maintain the structure and its adjacent areas on a regular basis. In general, a sand filtration basin of adequate design will requires a major maintenance effort every few years. Wet ponds will require inspections every few years and major maintenance when sediment removal is required.

The COA has studied other types of structural BMPs. Dry ponds (or sedimentation ponds), grassed channels or swales, and multi-chamber, large capacity oil and grit separators are all effective devices for pre-treatment of runoff waters.

7.2 Source Control Programs

Many of these programs, begun through the grant were part of the application package for the US EPA Region VI 1994 NPS Environmental Excellence Award Program received for the City's multifaceted approach to NPS control. The following section discusses some measures of success which reflect the opportunity and benefits provided by source control programs. The project team supports the contention that these programs are an essential and integral part of the City's water quality efforts and the project results support this claim.

7.2.1 Success of Public Outreach Program

Although it is difficult to quantify the effectiveness of outreach on water quality data, the responses to the programs were significant. The free posters were distributed at public functions through the City's Community Education division. During the first month after the news series and public service announcement (PSA) aired, over 900 calls were received on the voice-mail system, and over 1000 posters were mailed. During the next year, over 100 calls were received and posters sent out each month. The City also received group requests from companies including Motorola, IBM, 3M, AMD, AISD, Girl and Boy Scouts, and many other civic organizations. In May 1992, the City sent out 270,000 utility bill pamphlets containing a condensed version of the poster information. In addition, 120,000 half-sized posters were sent out with an issue of the local newspaper.

After each sponsored business seminar, the "Cut the Crud" training video was overwhelmingly rated "excellent" or "good" with only two percent rating it "poor." As a whole, the seminars were rated as being very beneficial to the business operators. Since the seminars, positive feedback has continued to be given to the City by the targeted audience with requests for more seminars in the future. In addition, the City has distributed over 50 video tapes upon public request, including requests from other environmental agency staff. In addition, the "Cut the Crud program was so well-received that when the City was developing its Annual Water Quality Campaign and poster Series for 1994, it was decided to use the same characters and slogan as with the previous education program for small businesses. Wider dissemination of these materials was completed, and each year a new water quality campaign is planned to be developed in response to the reaction to this first, grant funded pilot project.

7.2.2 Success of Citizen Monitoring Program

This program was successful in achieving its objectives by involving citizens in the process of aquatic research and monitoring. The level of awareness of nonpoint source problems, and related environmental issues was greatly increased through participation in this program. Nine of Town Lake's creeks were monitored.

Over 200 interns and volunteer monitors collected samples and documented their water quality monitoring data. Eight reports from different monitoring groups were generated. This program continues to expand and represents a baseline of specific creek data for use in watershed planning and prioritization.

7.2.3 Survey Recommendations

Recommendations were made from the survey to design educational public service announcements (PSAs) associated with NPS pollution which address the following areas:

- The physical mechanics and sources of NPS pollution
- Proper disposal of yard waste (organic matter), petroleum products, and household hazardous chemicals.
- The existence of the City of Austin Household Hazardous Waste Center
- The importance of properly applying fertilizers and pesticides, and
- Alternative environmentally friendly pest control products.

The emphasis on these topics should be increased in future education efforts based on lack of knowledge the respondents demonstrated on NPS problem.

REFERENCES

1. ADS Environmental Services, "QuadraScan User's Manual," July 1993.

2. American Sigma, "Operaion and Maintenance Manual for Model 950 Area Velocity Flow Meter," June 1995.

3. Baudo, R, Giesy, J., Muntau, H. 1990. Sediments: Chemistry and Toxicity of In-place Pollutants. Lewis Publishers, Boca Raton, Fl. Pg.7.

4. Bury and Pittman, Inc., "Barton Ridge Plaza Sedimentation/Filtration Ponds Construction Plan," Plan Coordinated with the City of Austin under Barton Ridge Ltd. Community Facilities Agreement (COA Water Quality Coordinator, Leslie Tull, P.E.), May 1988.

5. City of Austin, "Lake Austin Watershed Ordinance, Ordinance No. 80 0103-N," January 1980.

6. City of Austin, "Comprehensive Watershed Ordinance, Ordinance No. 0508-V," May 1986a.

7. City of Austin, "Stormwater Monitoring Program Description," Prepared by Water Quality Monitoring Section, Drainage Utility Department (formerly Environmental and Conservation Services Department - ECSD), November 1986b.

8. City of Austin, "Environmental Criteria Manual," June 1988a; Updated 1994.

9. City of Austin, "Drainage Criteria Manual," June 1988b.

10. City of Austin, "Removal Efficiencies of Stormwater Control Structures," Prepared by Environmental Resources Management Division, Drainage Utility Department (formerly ECSD), May 1990a.

11. City of Austin, "Stormwater Pollutant Loading Characteristics for Various Land Uses in the Austin Area," Prepared by Environmental Resources Management Division, Drainage Utility Department (formerly ECSD), March 1990b.

12. City of Austin, "The First Flush of Runoff and Its Effects on Control Structure Design," Prepared by Environmental Resources Management Division, Drainage Utility Department (formerly ECSD), June 1990c.

13. City of Austin, "Drainage Utility Business Plan," January 1992.

14. City of Austin, "Operation Manual for Stormwater Monitoring Program," A Training Manual for Water Quality Monitoring Section, Drainage Utility Department (formerly ECSD), May 1993a.

15. City of Austin, "Water Quality Monitoring Program Summary," Prepared by Water Quality Monitoring Section, Drainage Utility Department (formerly ECSD), May 1993b

16. City of Austin, "Urban Storm Water Discharge Characterization for the City of Austin Area," A Wet Weather Data Characterization Report Submitted to the U. S. Environmental Protection Agency (USEPA) for Compliance with the Requirements of the National Pollutant Discharge Elimination System (NPDES) Municipal Storm Water Discharge Permit Application, August 1994.

17. City of Austin, "Characterization of Stormwater Pollution for the Austin, Texas Area," Draft Report Prepared by Environmental Resources Management Division, Drainage Utility Department (formerly ECSD), August 1995a.

18. City of Austin, "Barton Creek Watershed Study," Draft Report Prepared by Environmental Resources Management Division, Drainage Utility Department(formerly ECSD), September 1995b.

19. City of Austin, "Stormwater Monitoring Program Descriptions, Schedules, and Site Locations," Prepared by Water Quality Monitoring Section, Drainage Utility Department, January 1996a.

20. City of Austin, "Waller Creek Basin Retrofit Study, an EPA Grant Project" Final Report Prepared for the U. S. Environmental Protection Agency (USEPA), March 1996b.

21. Driscoll, E. D., "Lognormality of Point and Non-Point Source Pollutant Concentrations," Urban Water Quality, Proceedings of an Engineering Conference, Published by the American Society of Civil Engineers, 1986.

22. Engineering Science and City of Austin, "Final Report of the Nationwide Urban Runoff Program in Austin, Texas," January 1983.

23. Herschy, R.W., "Streamflow Measurement," Elsevier Applied Science Publishers, New York, 1985.

24. ISCO, "Instruction Manual for Model 3230 Flow Meter," May 1990.

25. National Oceanic and Atmospheric Administration, The potential for biological effects of sediment-sorbed contaminants tested in the national status and trends program, PB91-172288, 1991

26. Schueler, T.R. et al., "A Current Assessment of Urban Best Management Practices, Prepared for USEPA, Office of Wetlands, Oceans, and Watersheds and Metropolitan Washington Council of Governments, December 1991.

27. Santos and Associates, "Barton Springs Zone Retrofit Masterplan Study. Austin, Texas," 1995.

28. Schueler, T. R., "Controlling Urban Runoff: A Practical manual for Planning and Designing Urban Best Management Practices," Metropolitan Washington Council of Governments Publication No. 87703, Washington, D.C., 1987.

29. Souer, C.J., J. Hubka, G. Chang, and S. Stecher, "Methods for assessing urban stormwater pollution", In: Proceedings of Engineering Foundation Conference, Torno, H.C., ed., American Society of Civil Engineers, New York, 1995.

30. United States Environmental Protection Agency (USEPA), National Sediment Contaminant Source Inventory: Point Analyses, Draft, 1994.

31. United States Environmental Protection Agency, "Results of the Nationwide Urban Runoff Program," Final Report, Vol. 1, Washington, D.C., 1983.